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Pollution Control Manual for Irrigated Agriculture

Toups Corp, Loveland, CO

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The manual is intended to expand understanding of irrigated agriculture-water quality relationships to a broad group, including water quality interests, water resource interests, and agricultural field technicians.

Information on collecting pertinent information on the irrigation system, sampling techniques, and evaluation techniques for determining the water quality impacts of return flows, combined with beneficial use aspects allow irrigation to be put into perspective with other elements of a water quality plan. Development of best management practices (BMP's) incorporate this water quality information plus information on the various agricultural practices. Understanding of local conditions affecting BMP's can be developed within the evaluation framework.

Technical information on irrigated agricultural practices and the pollutants associated with return flows is presented in a thoroughly-organized manner which makes it available to the layman as well as to experienced personnel. Traditional and recently developed irrigation practices are developed and evaluated in terms of use, pollutant loading pathways, cost, and effectiveness. Pollutants are discussed in terms of occurence in nature, loading mechanisms, evaluation techniques, and effect upon beneficial use.

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Water Pollution		Irrigation Management Practices	
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Sediment		Pollution Control Options	
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POLLUTION CONTROL MANUAL FOR IRRIGATED AGRICULTURE

Prepared by

Keith Kepler, P.E., Project Manager
Don Carlson, Project Engineer

W. Tom Pitts, P.E., Program Manager

Toups Corporation
1966 West 15th Street
Loveland, Colorado 80537

Project Officer
Mr. George Collins
Contract No. 68-01-3562

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TABLE OF CONTENTS

1.0 INTRODUCTION. 1

1.1 PURPOSE AND OBJECTIVES. 1

  1.1.1 The Federal Water Pollution Control Act and Irrigated Agriculture 2

1.2 PROBLEM STATEMENT 3

1.3 HOW TO USE THIS MANUAL. 4

1.4 IRRIGATED AGRICULTURE AND ASSOCIATED POLLUTION PROBLEMS IN THE UNITED STATES. 5

2.0 EVALUATION OF IRRIGATED AGRICULTURE AS A POLLUTANT SOURCE WITHIN THE REGION CONTEXT. . 26

2.1 THE PLANNING PROCESS. 26

2.2 STUDY AREA INVENTORY. 27

  2.2.1 Water Sources and Delivery Systems. . 29
  2.2.2 Water Quality and Quantity Information 32
  2.2.3 Irrigation Methods. 33
  2.2.4 Drainage Methods. 35
  2.2.5 Irrigated Areas 35
  2.2.6 Climatic Conditions 36
  2.2.7 Soils Data. 36
  2.2.8 Geologic Data 36
  2.2.9 Chemical Use. 37

2.3 PROBLEM DEFINITION. 37

3.0 DEFINITION OF BEST MANAGEMENT PRACTICES FOR IRRIGATED AGRICULTURE 39

3.1 SUB-REGIONAL VS. ON-FARM EVALUATION 41

3.2 DEFINITION OF POLLUTANT PATHWAYS. 42

3.3 CONTROL OPTION EFFECTIVENESS EVALUATION . . . 48

  3.3.1 Control Option Effectiveness Determination 49
  3.3.2 Effectiveness in Meeting Regional Goals 52

TABLE OF CONTENTS (CONT.)

3.3.3 Determination of Sub-Regional Best Management Practices. 53
3.3.4 Estimation of Reduction in Pollutant Loading 53
3.3.5 Determination of On-Farm Best Management Practices. 55

3.4 CASE STUDY - BEST MANAGEMENT PRACTICES FOR IRRIGATED AGRICULTURE IN THE LARIMER-WELD REGION OF COLORADO. 56

3.4.1 Water Quality Impacts of Irrigated Agriculture 56
3.4.2 Best Management Practices - Pollutant Loading Mechanisms. 58
3.4.3 Cost Effectiveness for BMP's in Larimer-Weld Region 60
3.4.4 Conclusion. 73

4.0 POLLUTANTS ASSOCIATED WITH IRRIGATION RETURN FLOW AND THEIR EFFECTS UPON BENEFICIAL USE. . 77

4.1 SOURCES AND LOADING MECHANISMS FOR POLLUTANTS EMANATING FROM IRRIGATED AGRICULTURE. 78

4.1.1 Salinity. 78
4.1.2 Sediment. 83
4.1.3 Nitrogen. 84
4.1.4 Phosphorus. 87
4.1.5 Pesticides. 90
4.1.6 Other Pollutants. 92

4.2 IDENTIFICATION OF WATER QUALITY PROBLEMS ASSOCIATED WITH IRRIGATED AGRICULTURE 93

4.2.1 Locating Return Flows 93
4.2.2 Determination of Return Flow Quality and Quantity. 95
4.2.3 Analysis of the Water Quality Impacts of Irrigation Returns 100

4.3 WATER QUALITY REQUIREMENTS FOR BENEFICIAL USES. 104

4.3.1 Irrigation Water. 105
4.3.2 Livestock Water 109
4.3.3 Domestic Use. 111

TABLE OF CONTENTS (CONT.)

4.3.4 Fisheries 114
4.3.5 Recreation. 115

5.0 IRRIGATED AGRICULTURAL PRACTICES AND POLLUTION CONTROL OPTIONS. 116

5.1 DELIVERY SYSTEMS. 116

5.1.1 Conveyance Systems. 116
5.1.2 Flow Measurement. 118

5.2 IRRIGATION APPLICATION SYSTEMS - DESCRIPTION.118

5.2.1 Furrow Irrigation 119
5.2.2 Border Strip Flooding 124
5.2.3 Level Basin Flooding. 124
5.2.4 Wild Flooding 125
5.2.5 Sprinkler Irrigation. 125
5.2.6 Drip Irrigation 126
5.2.7 Sub-Surface Irrigation. 127

5.3 IRRIGATION APPLICATION SYSTEMS - COMPARISON OF RETURN FLOW CHARACTERISTICS. 127

5.3.1 Furrow Irrigation 127
5.3.2 Border Irrigation 135
5.3.3 Level Basin Irrigation. 136
5.3.4 Wild Flooding 136
5.3.5 Sprinkler Irrigation. 138
5.3.6 Drip Irrigation 138

5.4 IRRIGATION MANAGEMENT AND EFFICIENCY. 138

5.4.1 Irrigation Management 138
5.4.2 Scientific Irrigation Scheduling. . .139

5.5 EXCESS WATER REMOVAL SYSTEMS. 146

5.5.1 Tailwater Systems 146
5.5.2 Drainage. 150

5.6 SOIL CONSERVATION PRACTICES 150

5.7 FERTILIZER RESOURCE MANAGEMENT. 152

5.8 EFFECTIVENESS AND COST OF POLLUTION CONTROL .153

TABLE OF CONTENTS (CONT.)

5.8.1 Salinity. 154
5.8.2 Nitrates. 154
5.8.3 Sediment. 154
5.8.4 Other Pollutants Associated with Surface Runoff. 160
5.8.5 Costs of Irrigated Agricultural Practices 160

6.0 WATER LAW 162

6.1 WATER QUALITY LAW 162

6.2 WATER ALLOCATION LAW. 163

6.2.1 Riparian Doctrine 165
6.2.2 Doctrine of Prior Appropriation 166
6.2.3 Ground Water Control Systems. 168
6.2.4 Related Law 169

6.3 EFFECTS ON BEST MANAGEMENT PRACTICES. 172

6.3.1 Water Quality Law Issues. 172
6.3.2 Water Quantity Law Issues 173

APPENDIX A - REFERENCES 176
APPENDIX B - GLOSSARY 194
APPENDIX C - PESTICIDES 199
APPENDIX D - CONVERSIONS AND CALCULATIONS 212

LIST OF FIGURES

Fig. #	Figure Title	Page
1-1	Irrigated Land, 1969.	7
1-2	Hydrologic Divisions.	9
1-3	Irrigated Areas, Great Basin.	11
1-4	Irrigated Areas, Upper Colorado River Sub-Basin	13
1-5	Irrigated Areas, Lower Colorado River Sub-Basin	15
1-6	Irrigated Areas, Arkansas-Red River Basin	17
1-7	Irrigated Areas, Rio Grande and Western Gulf Region.	19
1-8	Irrigated Areas, Missouri River Basin	21
1-9	Irrigated Areas, South Pacific Region	23
1-10	Irrigated and Potentially Irrigable Areas, Pacific Northwest Region.	25
2-1	BMP Manual Methodology - Identification of Water Quality Impacts of Irrigation Return Flow.	28
3-1	BMP Manual Methodology - Definition of Best Management Practices.	40
3-2	Major Pollutant Pathways.	43
3-3	Examples of Interrelationships.	46
4-1	Water and Salt Balance.	82
4-2	The Nitrogen Cycle.	85
4-3	Pathways of Fertilizer Phosphorus	88
4-4	The Phosphorus Cycle in Agriculture	89
4-5	Pesticide Cycling in the Environment.	91
4-6	Irrigated Agriculture Return Flows.	96

LIST OF FIGURES (CONT.)

Fig. # Figure Title Page

4-7 Correlation of Mapped Data. 102

4-8 Water Quality Analysis. 103

4-9 Diagram for the Classification of Irrigation Waters. .106

5-1 Irrigation Methods. 120

5-2 Advance Recession Curves for Surface Irrigation. 131

5-3 Surface Irrigation Soil Profile 132

5-4 Data Showing Relationship Between Irrigation Efficiency and Water Cost 140

5-5 Pond Length Required for Quartz Particles to Settle One Foot at Various Forward Velocities, Using Stokes Law. 149

6-1 Surface Water Law Systems in the Western States. .164

6-2 Ground Water Law Systems in the Western States. 170

LIST OF TABLES

Table #	Table Title	Page
1-1	20 Leading States by Number of Irrigated Acres: 1974	6
1-2	Distribution of Irrigated Land by Major Basin	5
2-1	Sources of Information	30
2-2	Kinds of Information	31
3-1	Summary of Factors Contributing to Pollutant Loading	44
3-2	Loading Mechanisms for Pollutants Associated With Irrigation Return Flow	45
3-3	Control Option Effectiveness Comparison - Example: Salinity	51
3-4	Ranking of Sub-Basin Alternatives and Cost Estimation	54
3-5	Pollutants Affected by BMP's	62
3-6	Loading-Reduction Effectiveness Factors	64
3-7	Capital Costs of BMP's	67
3-8	Annual Costs Per Acre	68
3-9	Annual Costs	70
3-10	Benefits Per Acre	71
3-11	Comparison of Effectiveness to Net Cost - Salinity	74
3-12	Comparison of Effectiveness to Net Cost - Nitrates	75
3-13	Comparison of Effectiveness to Net Cost - Sediment	76
4-1	Suitability of Waters for Irrigation	107
4-2	Relative Salt Tolerance of Various Crop Plants	108

LIST OF TABLES (CONT.)

Table #	Table Title	Page
4-3	Guide to the Use of Saline Waters for Livestock and Poultry	110
4-4	EPA Water Quality Standards for Discharge to Ground Waters Utilized as a Drinking Water Supply	112
5-1	Suitability of Irrigation Methods	128
5-2	Typical Return Flow Characterisitcs of Irrigation Methods	129
5-3	Concave Slope Results on Borders	137
5-4	Estimated Reduction in Pollutant Loading for Various Control Options as Compared to Furrow Irrigation	155
5-5	Average Water Losses to Deep Seepage for Irrigation Systems	157
5-6	Expected Sediment Loss Reduction for Selected Control Practices on Typical Irrigated Farms in the Magic Valley and Boise Valley	159
6-1	Characteristics of Water Rights in Western States	171

CHAPTER 1 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

Current interest in controlling the pollution load from irrigated agriculture has been brought about by:

- The Federal Water Pollution Control Act;
- The international agreement between the U.S. and Mexico concerning salinity levels in the Colorado River;
- Several significant regional and local problems where salts have reduced crop yield, nutrients have contributed to eutrophication of lakes or bays, or sediment has impaired water quality.

Understanding of the relationships between irrigated agriculture and water quality has been concentrated in a relatively small group at the research level. This manual is intended to expand understanding of irrigated agriculture-water quality relationships to a much broader group, including:

- Water quality planners and agencies;
- Water resource planners and agencies;
- Agricultural field technicians.

In order to do this, the manual presents:

- A brief look at irrigated agriculture in the Western United States, and the associated pollution problems;
- A methodology for evaluating the water quality impacts of irrigated agriculture within a region;
- A methodology for evaluating potential best management practices within the context of regional problems and regional goals;
- A discussion of the pollutants associated with irrigation return flow, their loading mechanisms, and effects upon beneficial use;
- A review of irrigated agricultural practices and associated pollutant loading mechanisms;
- A brief discussion of water law.

The presentation of technical information on pollutants, irrigation practices, and water law is not intended to be inclusive of all current knowledge and data. Rather, it is intended as background material for those who may not be directly engaged in irrigation return flow pollution control technology. In this way, it is hoped that the agriculturalist can develop an understanding of pollution aspects of irrigation and that water quality interests will develop an understanding of irrigated agriculture and the limitations of a stream imposed by irrigation water requirements.

1.1.1 The Federal Water Pollution Control Act and Irrigated Agriculture

1977 Amendments to the Federal Water Pollution Control Act (P.L. 92-500) have resulted in significant changes in the way irrigated agriculture is to be addressed. Provisions in Section 208 require that an areawide waste treatment management plan prepared under such process shall include:

> "a process to identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, including return flows from irrigated agriculture and their cumulative effects, runoff from manure disposal areas, and from land use for livestock and crop production, and set forth procedures and methods including land use requirements to control to the extent feasible such sources;" Section 208, (b)(2)(F)

These amendments also provide for a method of achieving best management practices. Public Law 92-500, Section 208, paragraph (j)(l) states:

> "The Secretary of Agriculture, with the concurrence of the Administrator, and acting through the Soil Conservation Service and other agencies...is authorized and directed to establish and administer a program to enter into contracts...for the purpose of installing and maintaining measures incorporating best management to control nonpoint source pollution for improved water quality in those States or areas for which the Administrator has approved a [208]plan..."

The Amendment goes on to explain administration of the document and to allow for funding to become available in Fiscal Year 1979.

The basic requirements for funding of nonpoint source best management practices as stated in Section 208 are then:

- A 208 Plan including a process to identify nonpoint sources including irrigated agriculture;
- A 208 Plan which sets forth procedures and methods to control nonpoint sources (Section 208, (b)(2)(F).

This manual focuses on development of information necessary to fulfill these requirements including:

- Identification of water quality problems associated with irrigated agriculture and identification of problem areas;
- Definition of best management practices within the local context.

The manual is intended to aid local areas in achieving these requirements. Through development of sound programs, funds provided under the 1977 Amendments can become available to 208 agencies and can be used effectively.

1.2 PROBLEM STATEMENT

Problems involved in the definition of water quality problems associated with irrigation returns, definition of best management practices, and implementation of best management practices are many. These problems include:

- Lack of data on the quality of returns in many areas;
- Lack of perspective on agricultural water problems in many basin plans;
- Methodology for data collection and evaluation of water quality problems in irrigated areas has not been adequately brought forth;
- In many instances, technology is yet developing. Utilization of soils data in water quality studies is one such area;
- Designated 208 areas often have an urban base; as a result, emphasis may have been directed towards urban problems;
- Prediction of results obtained through implementation of best management practices cannot be conducted with a high degree of accuracy under current technology; monitoring results is equally difficult;
- The major water quality problem associated with irrigation in the West is salinity - for the most part this is the inevitable result of consumptive use. As a result, best management practices for irrigation

can only hope to reduce that small portion of salt concentrations due to non-beneficial or excessive consumptive use. Natural salt sources and saline soils contribute to salt load in a few areas, both irrigated and non-irrigated, but these are also quite difficult to control.

1.3 HOW TO USE THE MANUAL

This manual is intended to give an overview of the technology involved in evaluating and reducing pollutants associated with irrigation return flow and to provide a methodology which can tie the technical steps into a planning process.

In order to do this, the manual has been divided into six chapters:

Chapter 1 - Introduction
Chapter 2 - Evaluation of Irrigated Agriculture as a Pollutant Source Within the Regional Context
Chapter 3 - Definition of Best Management Practices for Irrigated Agriculture
Chapter 4 - Pollutants Associated with Irrigated Agriculture and Their Effects Upon Beneficial Uses
Chapter 5 - Irrigated Agriculture Practices and Pollution Control Options
Chapter 6 - Water Law

Chapters 2 and 3 present a methodology for evaluation of water quality impacts resulting from returns and evaluation of best management practices. These chapters form the center of this report. While each area will require a methodology adapted to its own needs, the basic steps are not expected to vary significantly from those shown in Figures 2-1 and 3-1.

Chapters 4 and 5 provide background technical information. Chapter 6 provides a brief introduction to water law aspects of irrigated agricultural pollution control. This information has been presented in a manner which should make it widely available. More detailed information can be gained from the references.

Efficient use of nonpoint source control dollars requires educated agricultural field personnel, and it is hoped that this manual will serve the Soil Conservation Service and other agencies in this capacity.

The methodology has been developed primarily through the consultant's experience in northern Colorado. In this area, 208 work has included not only a technical definition of problems and best management practices, but also a social-institutional study. Institutional assignments have been made concerning planning, management, operations, and enforcement. Current work is being focused on the assignment of specific tasks to the agencies which will soon have implementation responsibilities.

1.4 IRRIGATED AGRICULTURE AND ASSOCIATED POLLUTION PROBLEMS IN THE UNITED STATES

A combination of social, economic, and physical factors determine the feasibility of crop irrigation. Social and economic factors demand intensified and stable crop production. Physical factors determine both the need for and feasibility of crop irrigation in an area. More than 90 percent of the total acreage irrigated on all farms in the nation are located in the 17 western states and Louisiana. Table 1-1 displays a breakdown of irrigated acreages in the twenty leading irrigation states. Figure 1-1 shows irrigated areas in the United States.

Irrigated land in the western states is distributed in eight major river basins (Figure 1-2). Table 1-2 shows the distribution of irrigated land within these basins.

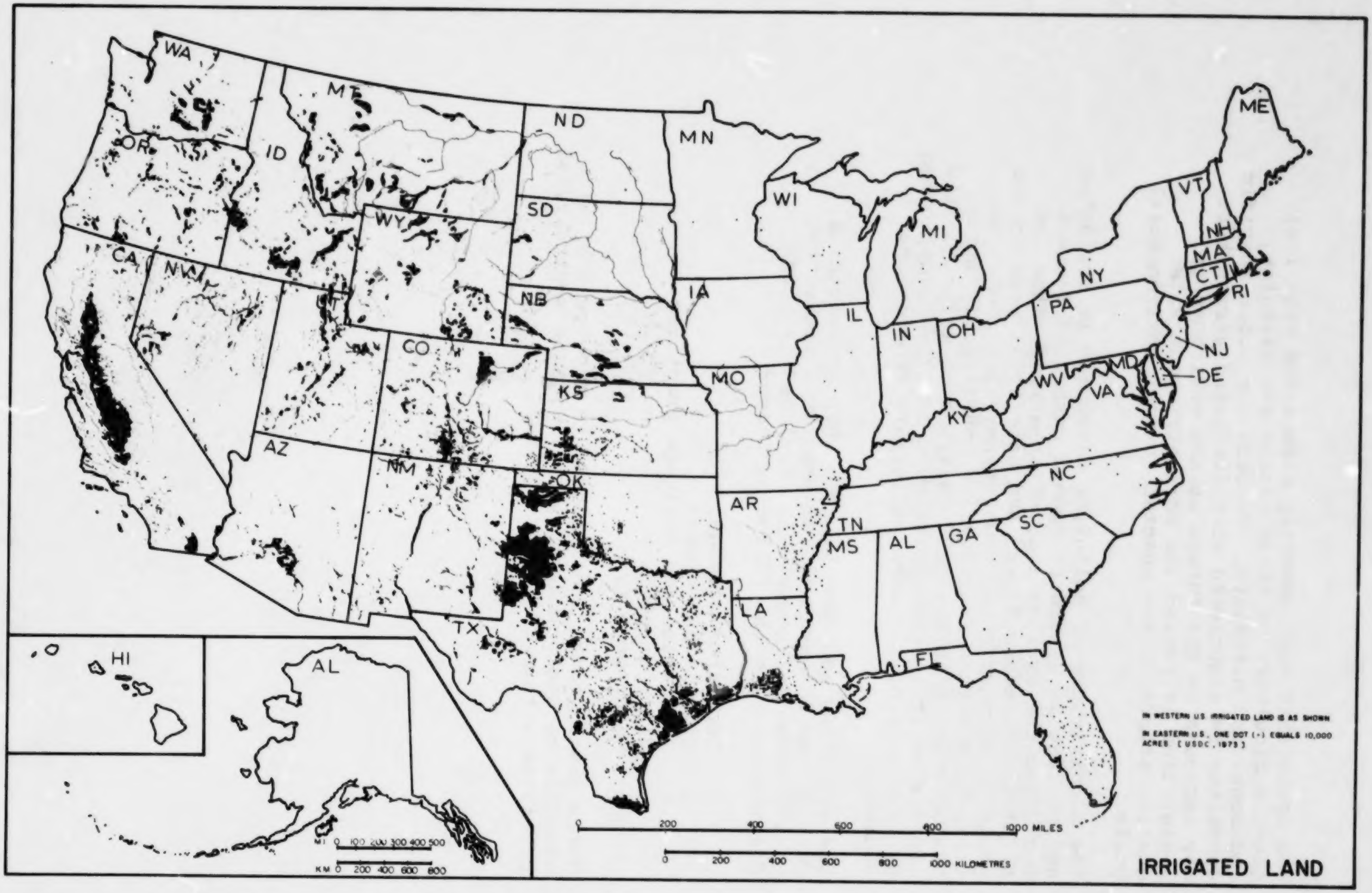
TABLE 1-2. DISTRIBUTION OF IRRIGATED LAND BY MAJOR BASIN

REGION	APPROXIMATE IRRIGATED LAND (million acres)
Great Basin	1.6
Colorado	
Upper Colorado	1.5
Lower Colorado	1.2
Arkansas Red River	4.2
Rio Grande - Western Gulf	6.2
Missouri	9.0
South Pacific	7.8
Pacific Northwest	5.7
TOTAL	37.3

TABLE 1-1 20 LEADING STATES BY NUMBER OF IRRIGATED ACRES: 1974 (a) (b)

Rank	Irrigated Acres (c)	Percent of all Irrigated Acres	Change Since 1969 + or - % (d)
United States	41,243,023	100	+ 3.1
20 Leading States	39,948,099	9.9	+ 5.0
1 California	7,748,709	18.8	+ 7.0
2 Texas	6,593,832	16	- 4.2
3 Nebraska	3,966,930	9.6	+49.0
4 Colorado	2,873,692	9.6	- 0.7
5 Idaho	2,859,047	6.9	+ 3.6
6 Kansas	2,010,385	4.8	+32.0
7 Montana	1,759,040	4.2	- 4.3
8 Oregon	1,561,438	3.8	+ 2.7
9 Wyoming	1,459,900	3.5	- 6.0
10 Florida	1,558,735	3.8	+14.0
11 Washington	1,309,018	3.2	+ 6.9
12 Arizona	1,153,478	2.8	- 2.0
13 Utah	969,645	2.3	- 5.5
14 Arkansas	948,910	2.3	- 6.1
15 New Mexico	867,325	2.1	+ 5.5
16 Nevada	777,510	1.9	+ 3.3
17 Louisiana	701,587	1.7	0
18 Oklahoma	515,104	1.2	- 1.7
19 Mississippi	161,611	0.4	+ 7.8
20 South Dakota	152,203	0.4	+ 2.7

(a) All Farms.
(b) U.S. Department of Commerce, 1974, Census of Agriculture.
(c) Hectares = .4047 x acres.
(d) U.S. Department of Commerce, 1969, Census of Agriculture.


IRRIGATED LAND
IN WESTERN U.S. IRRIGATED LAND IS AS SHOWN
IN EASTERN U.S., ONE DOT (•) EQUALS 10,000 ACRES (USDC, 1973)
0 200 400 600 800 1000 MILES
0 200 400 600 800 1000 KILOMETRES
MI 0 100 200 300 400 500
KM 0 200 400 600 800
WA
OR
CA
NV
ID
MT
WY
UT
CO
AZ
NM
ND
SD
NB
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
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NJ
CT
RI
MA
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NH
ME
AL
HI

FIGURE 1-1. IRRIGATED LAND, 1969 (A)
(A) 1969 Census of Agriculture

TOUPS CORPORATION
Loveland, Colorado

The pollutants most commonly associated with irrigated agriculture in these basins are salinity, sediment, and nutrients. Concern for other specific constituents associated with irrigated agriculture may increase in the future as new environmental legislation is passed and more stringent water quality standards are enacted to meet environmental goals.

The significance of pollutant discharge in irrigated agriculture is dependent upon a number of factors including the availability of in-stream water for dilution of return flows and beneficial uses at the point of discharge and downstream. The impact of irrigation return flows varies considerably among basins and within basins. Analysis of water quality impacts of irrigated agriculture is often complicated by discharge of the same pollutants from natural sources.

The remaining sections of this chapter provide a description of agricultural practices within the basins shown in Figure 1-2. Included in these descriptions are the following items:

- Irrigated acreage;
- Climate and crops;
- Irrigation and drainage practices;
- Water supply;
- Water quality.

These descriptions are intended to provide a brief synopsis of characteristics of irrigated agricultural practices within the eight regions.

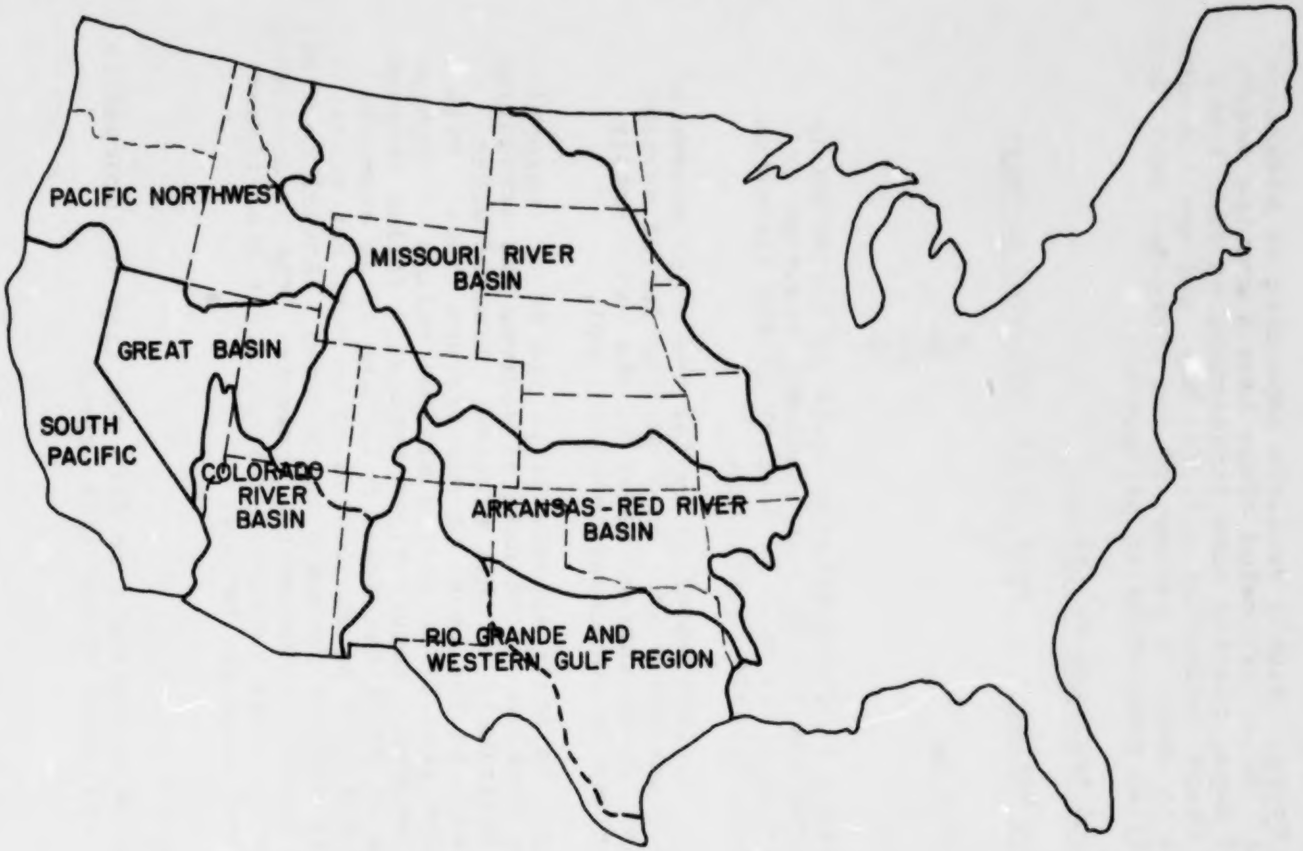
PACIFIC NORTHWEST
MISSOURI RIVER BASIN
GREAT BASIN
SOUTH PACIFIC
COLORADO RIVER BASIN
ARKANSAS-RED RIVER BASIN
RIO GRANDE AND WESTERN GULF REGION

FIG. 1-2. HYDROLOGIC DIVISIONS [A]

[A] USGS, 1966

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GREAT BASIN

Irrigated Acreage: Approximately 1.6 million acres (a)

Climate and Crops: Highly variable depending on elevation and latitude. Major irrigated areas have a growing season from 100-175 days, placing some limitations on crop types. Close grown crops (primarily alfalfa, hay, and small grains) are utilized on about 70 percent of the irrigated land, and approximately 24 percent is in pasture(b).

Irrigation and Drainage Practices:

Irrigation Method	Percent of Irrigated Acreage
Sprinklers	8
Furrows or Ditches	30
Flooding	61
Subirrigation	1

The predominance of close growing crops is reflected in the high percentage of flood irrigation. Drainage is required in many areas with 14 percent of the irrigated land utilizing drainage facilities.

Water Supply: Surface water is by far the major source of supply. The Great Basin area is a combination of several closed basins. Since surface water is the major supply source, water use is commensurate with supply.

Water Quality: Salinity appears to be the major regional water quality problem. Both natural sources and irrigation return flow contribute to this problem. Limited water resources result in the reuse of most return flows. This system of reuse results in only a minimal volume of highly-mineralized returns. Return flows typically follow streams to dead lakes of which the Great Salt Lake is an example. These dead lakes must be considered to be nutrient sinks, since nutrient outflow pathways are minimal. Actual nutrient problems are largely undocumented, however. The predominance of close growing crops indicates that nutrient (fertilizer) use and nutrient loss may be low.

(a) 1969 Census of Agriculture data modified to incorporate changes indicated by the 1974 census.

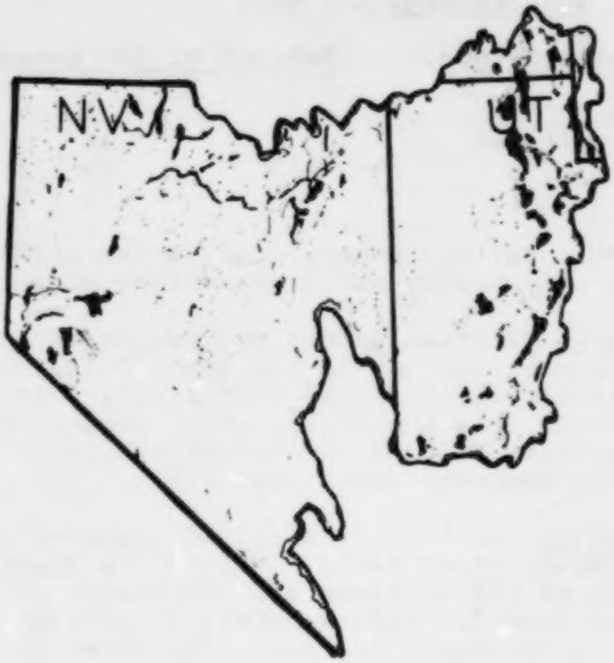


FIGURE 1-3. IRRIGATED AREAS, GREAT BASIN

UPPER COLORADO RIVER BASIN

Irrigated Acreage: Approximately 1.45 million acres(a)

Climate and Crops: Climate is widely varying depending upon elevation and latitude. A wide variety of crops are grown, although some climatic restrictions exist throughout the Upper Colorado area.

Irrigation and Drainage Methods:

Irrigation Method	Percent of Irrigated Acreage(a)
Sprinklers	4
Furrows or Ditches	49
Flooding	46
Subirrigation	1

The fact that surface waters provide the primary source results in only a very small percentage of sprinkler irrigation.

Water Supply: Surface waters provide nearly all supply water for irrigation use in the Upper Colorado River Basin. Mountain runoff supplies the bulk of this water, with only minimal runoff from the desert which occurs at lower elevations. Approximately 37 percent of irrigated lands receive less than an adequate water supply(b).

Water Quality: Salinity has been a topic of major concern in the Colorado River Basin. Within the Upper Colorado Basin, many of the problems are the result of natural springs and surface runoff. Approximately 37 percent of the total salt load at Lee Ferry has been attributed to irrigation, with most of the rest attributal to natural sources. The geology of the area is the primary complication, both for the irrigated and natural salt load. Average TDS concentration at Lee Ferry is 586 mg/l(b).

(a) 1969 Census of Agriculture data modified to incorporate changes indicated by the 1974 census.
(b) Toups Corporation, 1975.

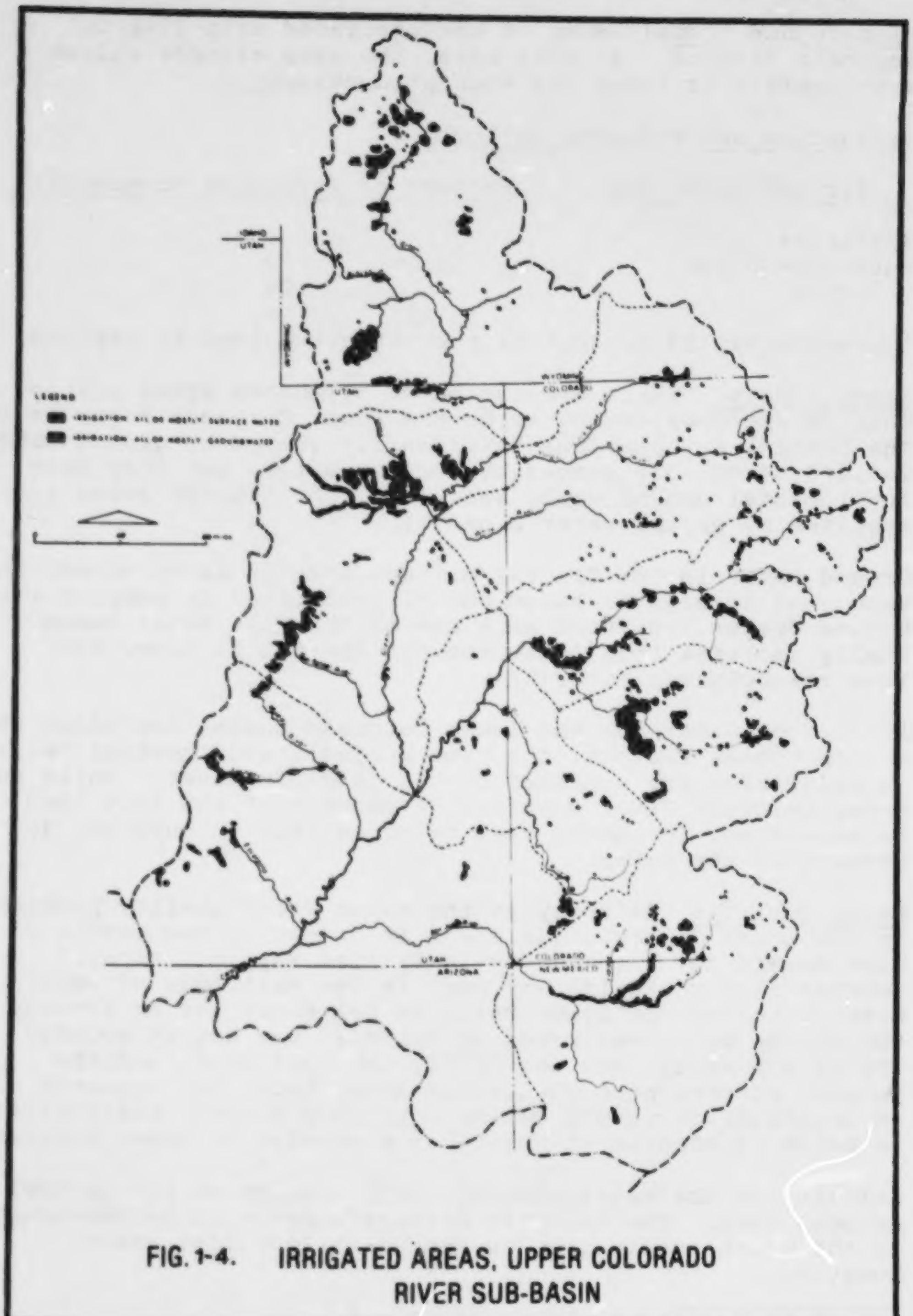

IDAHO
UTAH
WYOMING
UTAH
COLORADO
LEGEND
IRRIGATION ALL OR MOSTLY SURFACE WATER
IRRIGATION ALL OR MOSTLY GROUNDWATER
UTAH
ARIZONA
COLORADO
NEW MEXICO

FIG. 1-4. IRRIGATED AREAS, UPPER COLORADO RIVER SUB-BASIN

LOWER COLORADO BASIN

Irrigated Acreage: Approximately 1.24 million acres(a)

Climate and Crops: Most of the irrigated area lies in southern Arizona. In this area, the warm climate allows a wide variety of crops and high productivity.

Irrigation and Drainage Methods:

Irrigation Method	Percent of Irrigated Acreage(a)
Sprinkler	4
Furrow or Ditch	70
Flooding	26

Approximately 13 percent of the irrigated land is drained.

Water Supply: There are two major irrigated areas within what we are considering to be the Lower Colorado River Basin. The Central Arizona Area is primarily served by ground water. 206,000 acres are served by surface water, but they have supplemental ground water available, and 575,000 acres are supplied by ground water alone(b)

Ground water in the Central Arizona area is being mined, and each year acreage is taken out of production as pumping levels become deeper. Painted Rock Dam on the Gila River essentially isolates this area from the lower Gila River and from the Colorado River(b).

Irrigation water for the lower Colorado Basin, including the Welton Mohawk Project, the Yuma Project, and Imperial Valley in California are supplied by the Colorado River. While the Upper Colorado River supplies 72 percent of the salt load to this area, it should also be noted that it supplies 90 percent of the water.

Water Quality: Salinity is the major water quality problem in the Lower Colorado Basin and is primarily the result of high demand for a commodity in limited supply. Natural sources play a significant part in the salt load as well. Water entering the Lower Basin at Lee Ferry has an average TDS of 586 mg/l, and water at Imperial Dam has an average TDS of 839 mg/l. The use of all the good water and the pumping of very poor quality drainage water has resulted in an inability to supply Mexico with good water. Desalinization is being planned to alleviate this problem at great expense(c).

Salinity is the major water quality problem in the Central Arizona area. The salinity problem appears to be secondary to the water supply problem except in localized areas, however.

(a) Census of Agriculture, 1969 and 1974.
(b) John Erickson.
(c) Toups Corporation 1975.

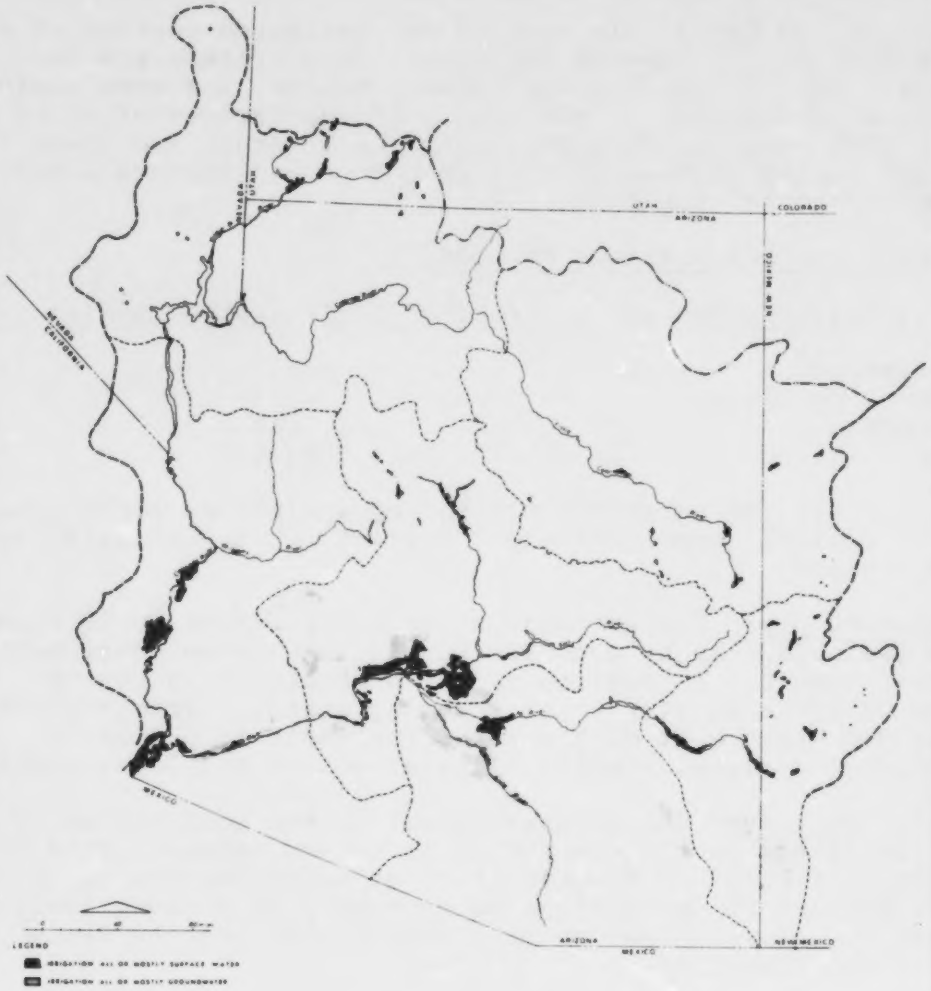

NEVADA
UTAH
UTAH
ARIZONA
COLORADO
NEW MEXICO
NEVADA
CALIFORNIA
MEXICO
ARIZONA
MEXICO
NEW MEXICO
0
40
80 mi
LEGEND
IRRIGATION ALL OR MOSTLY SURFACE WATER
IRRIGATION ALL OR MOSTLY GROUNDWATER

FIG. 1-5. IRRIGATED AREAS, LOWER COLORADO RIVER SUB-BASIN

ARKANSAS-RED RIVER BASINS

Irrigated Acreage: Approximately 4.2 million acres(a)

Climate and Crops: In most of the irrigated portion of the Basin, long hot summers and short, cold winters are the rule. The climate becomes warmer, milder, and more humid as one gets closer to the Gulf. A wide variety of crops are grown ranging from corn, hay, small grain and truck crops in the western portion to cotton and peanuts along the Oklahoma-Texas border.

Irrigation and Drainage Methods:

Irrigation Method	Percent of Irrigated Land(a)
Sprinkler	15
Furrow or Ditch	71
Flooding	14
Subirrigation	less than 0.5

Nearly all the acreage irrigated by sprinklers lies on the high plains. Approximately 5 percent of the irrigated land is drained.

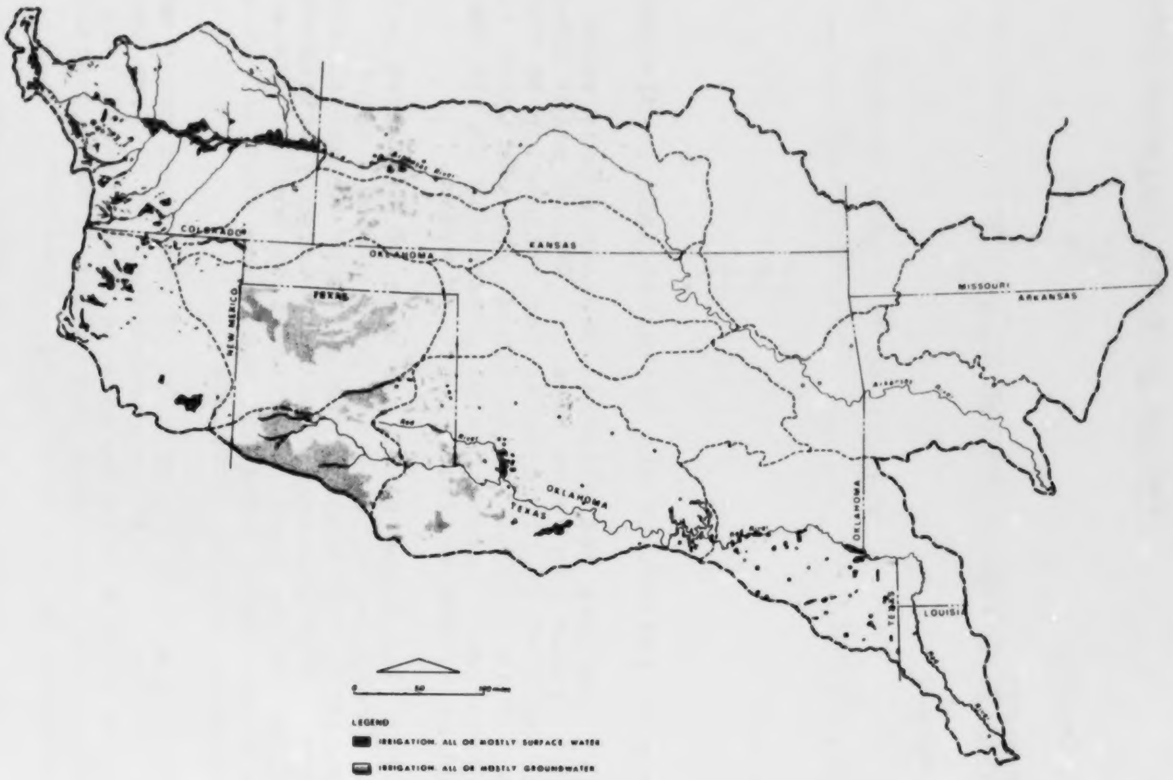
Water Supply: The Arkansas River and alluvium in Colorado is fed primarily by mountain runoff, with some contributing local runoff. Irrigation on the high plains is fed by the Ogallala aquifer which is being mined. Irrigation along the Red River east of the Texas Panhandle is primarily supplied by local runoff, alluvial wells, and local aquifers.

Water Quality: The Arkansas River is the most saline of major rivers in the country as it enters Kansas. This has been attributed to concentration of salts through reuse (85 percent of the surface water supply is consumptively used in Colorado) and natural salt pickup between Canon City and Pueblo(b).

Irrigation on the high plains has little effect on surface waters. Aquifer depletion presents a problem, however. The Red River and Arkansas River and their tributaries are all affected by natural brine emissions. Oil field brine emissions also contribute to the salt load in some areas.

(a) Census of Agriculture, 1969 with available 1974 data incorporated.

(b) Miles, Don. Salinity in the Arkansas Valley of Colorado, Colorado State University and U.S. EPA. 1977.



COLORADO
KANSAS
MISSOURI
ARKANSAS
OKLAHOMA
TEXAS
NEW MEXICO
LOUISIANA
Red River
Arkansas River
0
50
100 miles
LEGEND
IRRIGATION, ALL OR MOSTLY SURFACE WATER
IRRIGATION, ALL OR MOSTLY GROUNDWATER

FIG. 1-6. IRRIGATED AREAS, ARKANSAS — RED RIVER BASIN

RIO GRANDE AND WESTERN GULF REGION

Irrigated Acreage: Approximately 6.2 million acres(a)

Climate and Crops: Widely varied depending upon elevation, latitude, and proximity to the Gulf of Mexico.

Crop Types:

Crop	Percent of Total Irrigated Acreage(a)
Row Crops	67
Close Grown Crops	24 (1)
Tree Crops	1
Irrigated Pasture	8

(1) Including rice (about 550,000 acres)

Irrigation Method:

Irrigation Method	Percent of Irrigated Acreage With This Method (a)
Sprinkler	18
Furrow or Ditch	59
Flooding	22
Subirrigation	1

Approximately 13 percent of the irrigated land is drained.

Water Supply: Surface and alluvial sources supply water along the Rio Grande and Pecos Rivers. Ground water from the Ogallala aquifer supplies water for irrigation on the high plains. This water is being mined, and the water table is lowered each year. Areas draining directly to the Gulf are supplied by either surface or ground water.

Water Quality: The Pecos River has some of the worst problems in the U.S. Irrigated agriculture contributes significantly to salinity problems and to a lesser extent to sediment problems. High sediment loads are largely attributable to runoff from grazing land. Natural salt sources are abundant in the Pecos Basin. The extremely low rainfall is at the root of many water quality problems.

The Rio Grande displays the effects of continued reuse of waters for irrigation. TDS concentrations at El Paso vary considerably with flows attributable to irrigation return (winter) from 1,000-2,000 mg/l and summer flows augmented by reservoir releases in the 600-700 mg/l range(b).

While high plains irrigation has little effect upon surface water, depletion of the aquifer represents a significant problem.

(a) Census of Agriculture 1969 and 1974.
(b) Toups Corporation 1975.

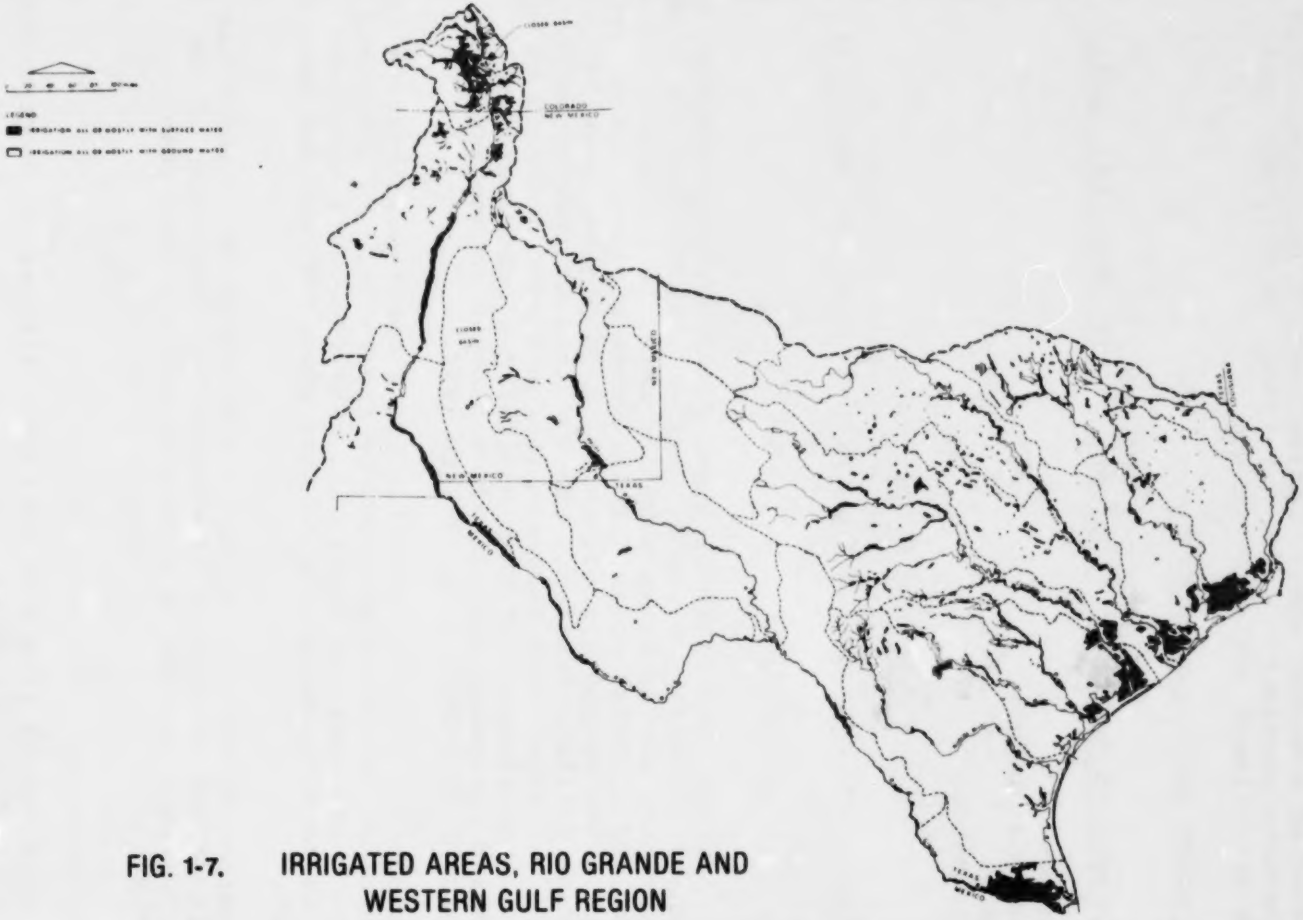

0 20 40 60 80 100 MILES
LEGEND
IRRIGATION ALL OR MOSTLY WITH SURFACE WATER
IRRIGATION ALL OR MOSTLY WITH GROUND WATER
CLOSED BASIN
COLORADO
NEW MEXICO
CLOSED BASIN
NEW MEXICO
TEXAS
NEW MEXICO
MEXICO
TEXAS
LOUISIANA
TEXAS
MEXICO

FIG. 1-7. IRRIGATED AREAS, RIO GRANDE AND WESTERN GULF REGION

MISSOURI RIVER BASIN

Irrigated Acreage: Approximately 9 million irrigated acres(a)

Climate and Crops: The continental climate includes hot summers and cold winters. The growing season is further complicated by somewhat eratic spring weather in the northern and western portions. Corn, hay, small grains, and sugar beets are primary irrigated crops.

Irrigation and Drainage Methods:

Irrigation Practices

Irrigation Method	Percent of Irrigated Acreage(a)
Sprinkler	21
Furrow and Ditches	52
Flooding	26
Subirrigation	1

Drainage Practices

Irrigation Method	Percent of Land Irrigated By This Method Which is Drained(a)
Sprinkler	2
Other Methods	10

Water Supply: The Missouri River Basin actually consists of two major irrigation systems. Surface runoff from the Rockies and the rest of the basin supplies water to irrigators along rivers and alluvial areas. This system receives annual recharge. The second system, on the high plains, overlies the vast Ogallala aquifer. The Ogallala aquifer is being drained of water with recharge insignificant compared to withdrawal. Development of this aquifer has contributed to increased irrigated acreage of 49 percent in Nebraska and 32 percent in Kansas from 1969 to 1974.

Water Quality: Salinity is the major problem in streams and alluvium of irrigated portions of the Basin. Nutrient and sediment problems are localized. The region is large and data is lacking, partially because problems have not become severe.

Irrigation on the high plains - much of it sprinkler - has little effect on surface water quality. Depletion of the deep Ogallala aquifer is a more serious problem than pollution.

(a) 1969 Census of Agriculture Data altered to incorporate available 1974 data.

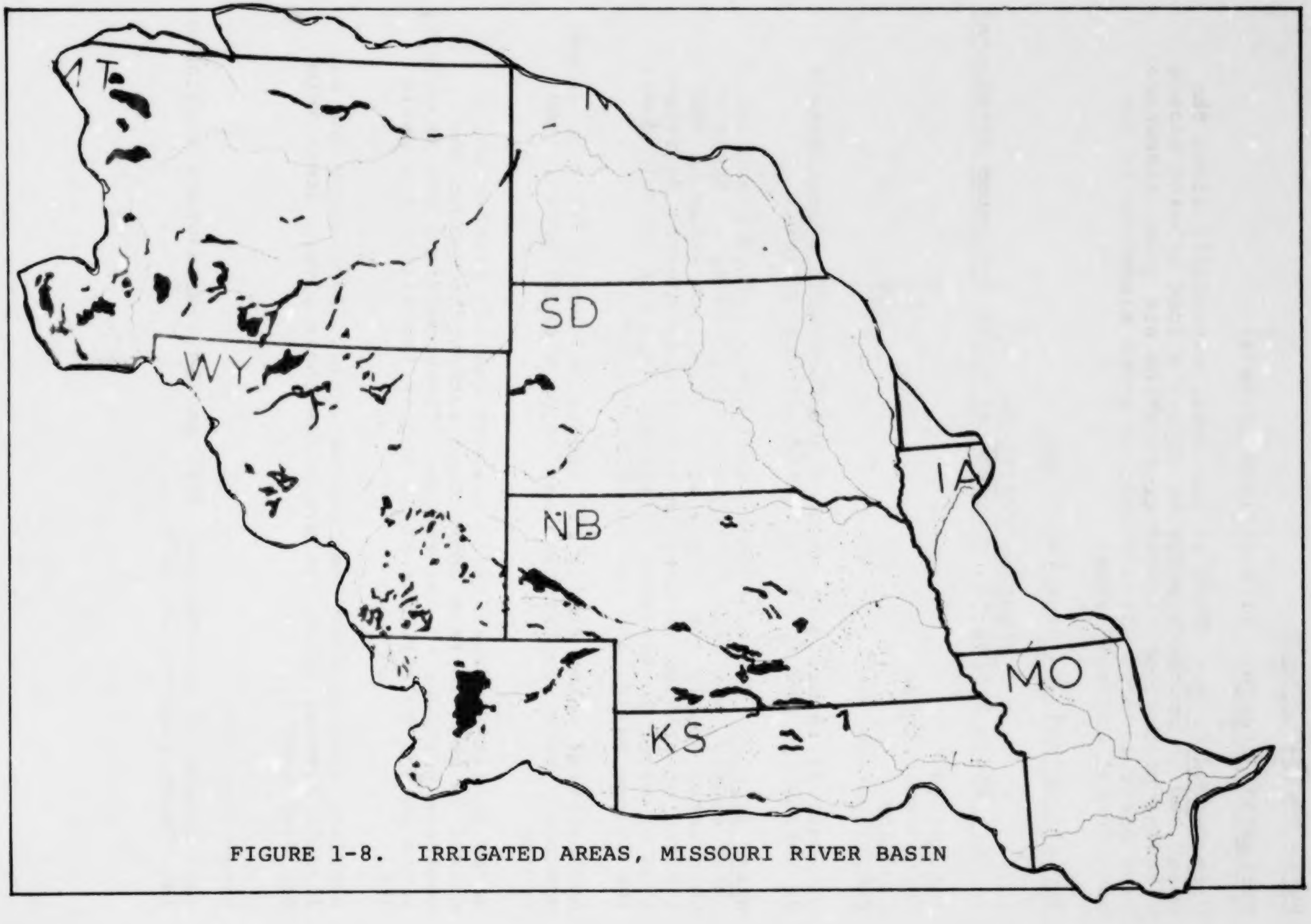

SD
WY
NB
IA
MO
KS

FIGURE 1-8. IRRIGATED AREAS, MISSOURI RIVER BASIN

SOUTH PACIFIC REGION

Irrigated Acreage: 7.75 million acres(a)

Climate and Crops: Much of the area, especially along the coast and in southern portions enjoys a long growing season allowing production of most crops which are grown elsewhere, plus several crops which cannot be grown elsewhere in the continental United States.

Irrigation and Drainage Practices:

Irrigation Practices

Irrigation Method	Percent of Total Irrigated Acreage(a)
Sprinklers	18
Furrow or Ditches	43
Flooding	38
Subirrigation	1

Drainage is required on much of the land with approximately 25 percent of the total irrigated acreage drained.

Water Supply: While northern California enjoys plentiful water supply, southern California has problems in terms of both water supply and supply water quality. Reuse of the limited quantities results in significant mineral degradation of water in southern California (the San Joaquin Basin, the Tulare Basin, and the Imperial Valley).

Agricultural water supply has undergone encroachment by urban demands. Water importation has major significance in the region.

Water Quality: Salinity is a water quality problem which exists in both surface and ground waters throughout the southern portions of the region. These portions are especially acute in the Tulare Lake Basin and in the Salton Sea Basin (b).

Nutrient loading from the Central Valley (Sacramento and San Joaquin Rivers) is of concern since these rivers drain into San Francisco Bay.

(a) Census of Agriculture, 1969 and 1974 data where available.
(b) Toups Corporation 1975.

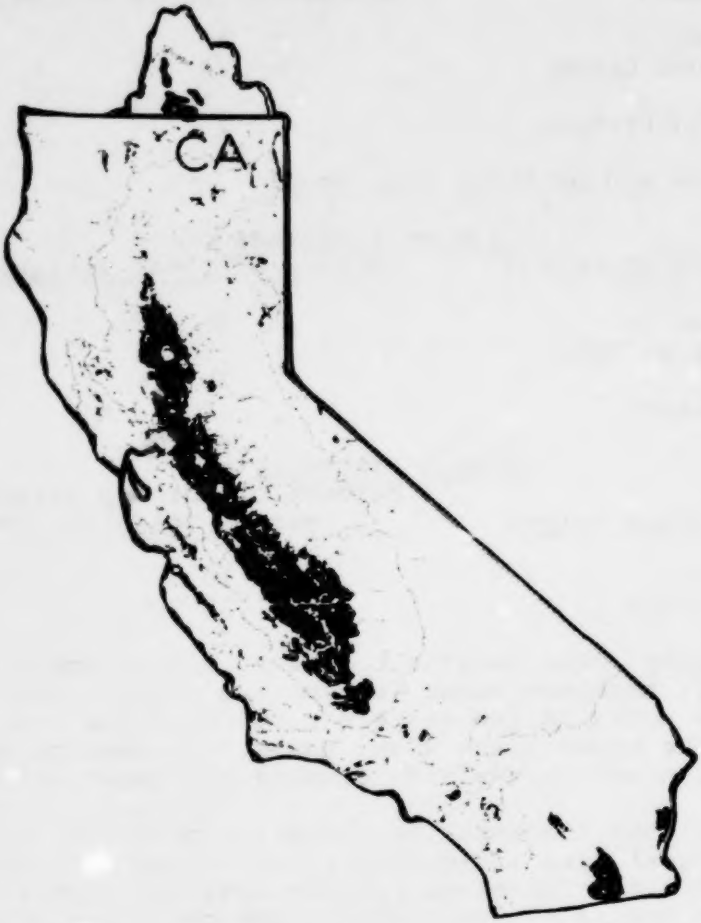


FIGURE 1-9. IRRIGATED AREAS, SOUTH PACIFIC REGION

PACIFIC NORTHWEST

Irrigated Acreage: Approximately 5.75 million acres(a)

Climate: Range of frost-free days dependent upon elevation.

Crops: Irrigated crop types are as follows: (a)

Crop Type	Percent of Total Acreage
Row Crops	16
Close Grown Crops	59
Tree	5
Irrigation Pasture	20

Irrigation and Drainage Practices:

Irrigation Practices (a)

Irrigation Method	Percent of Total Irrigated Acres(a)
Sprinklers	34
Furrow or Ditches	38
Flooding	26
Subirrigation	2

Drainage Practices

Irrigation Method	Percent of Acreage Irrigated by This Method Which Are Drained(a)
Sprinklers	10
Other Methods	12

Water Supply: The Pacific Northwest has an ample supply of water, but problems occur in time and place. Shortages of water are noted in the eastern portion of the region, particularly the Upper Snake River Basin. Inadequate ground water supply is noted in the Mid-Columbia and Upper Columbia areas.

Water Quality: Sediment is the major pollutant problem in the Northwest, and irrigation return flows are largely responsible. Sediment problems are particularly significant in the Snake and Yakima Rivers. Within the region, significant research on combating problems has been conducted by the land grant universities, U.S.D.A.-ARS, U.S.D.A.-SCS, and others.

Salinity is not an areawide problem. Salinity problems appear to be confined to upper river reaches to the east central portion of Washington and in closed basins. Sodium and salinity problems occur in a few tributaries south of the Snake River in Idaho.

Nutrient problems occur in several locations throughout the region.

(a) Census of Agriculture 1969 and 1974 data.

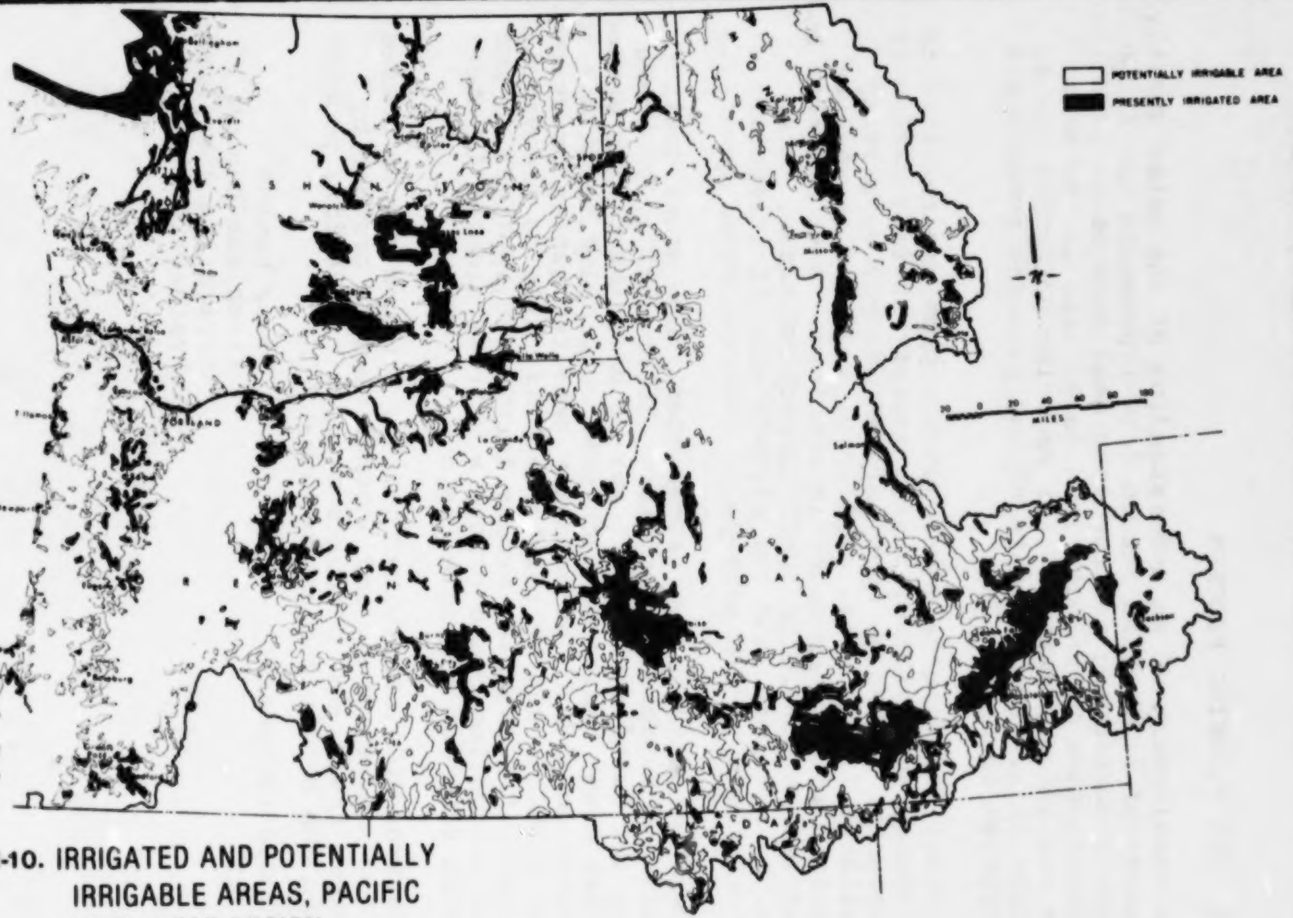

POTENTIALLY IRRIGABLE AREA
PRESENTLY IRRIGATED AREA
N
20 0 20 40 60 80 100
MILES
Bellingham
Astoria
PORTLAND
Tillamook
Newport
Coos Bay
La Grande

FIG.1-10. IRRIGATED AND POTENTIALLY IRRIGABLE AREAS, PACIFIC NORTHWEST REGION

2.0 EVALUATION OF IRRIGATED AGRICULTURE AS A POLLUTANT SOURCE WITHIN THE REGIONAL CONTEXT

2.1 THE PLANNING PROCESS

The development of an understanding of the water quality impacts of irrigation return flow represents the first step in developing and applying best management practices. Understanding of impacts in a local area is the basis for assigning priorities for reducing pollution due to return flow. Key elements of the planning process are displayed in Figure 2-1.

In order to evaluate water quality problems relative to irrigated agriculture, a wide variety of information is necessary. Although much information may be already available for an area, additional information will be required to address specific problems. Data can then be analyzed to determine specific problem areas, water quality problems, and the significance of irrigation return flows in the make-up of regional water quality.

The manual methodology is dependent upon water quality goals and regional priorities. Water quality problems from irrigated agriculture may be associated with either entire river basins or much smaller problem units due to natural conditions or commonly used irrigation practices. Some problems can be related specifically to individual fields. For example, excess fertilizer application and over irrigation could create a nitrate problem in the return flow for a single field.

Understandably, one water quality problem may be caused by one problem area, and another quality problem by another area. For purposes of this evaluation, problem areas can be divided as follows:

Sub-regional	River basins River sub-basins Irrigation districts Drainage districts

On-farm	Groups of adjacent farms Individual farms Individual fields Areas within single fields

During the planning and program direction phase of an evaluation process, a progression is made from "sub-regional" areas to "on-farm" areas. However, implementation steps often proceed from "on-farm" areas to "sub-regional" areas.

While the solutions to water quality problems within the suggested problem areas may be the most reasonable and practicable, there may be prohibitive institutional constraints. Political areas, defined by county or state boundaries, generally have adequate legal tools and organizations to implement programs more easily than geographical areas. Regional, statewide, and perhaps joint-state 208 planning is an excellent mechanism for developing solutions to agricultural pollution problems.

2.2 STUDY AREA INVENTORY

In order to analyze water quality problems and to recommend best management practices, existing irrigation practices and environmental conditions must be inventoried. Much information is available but disposed among various disciplines:

Agriculture
Hydrology
Geology
Biology
Economics
Law
Soils
Chemistry
Land use
Engineering
Water quality
Agronomy
Atmospheric science
Environmental health
Water resources
Planning

Information within these areas relative to irrigation return flow can be found at various levels of government and in the private sector. Table 2-1 contains a list of potential sources of information.

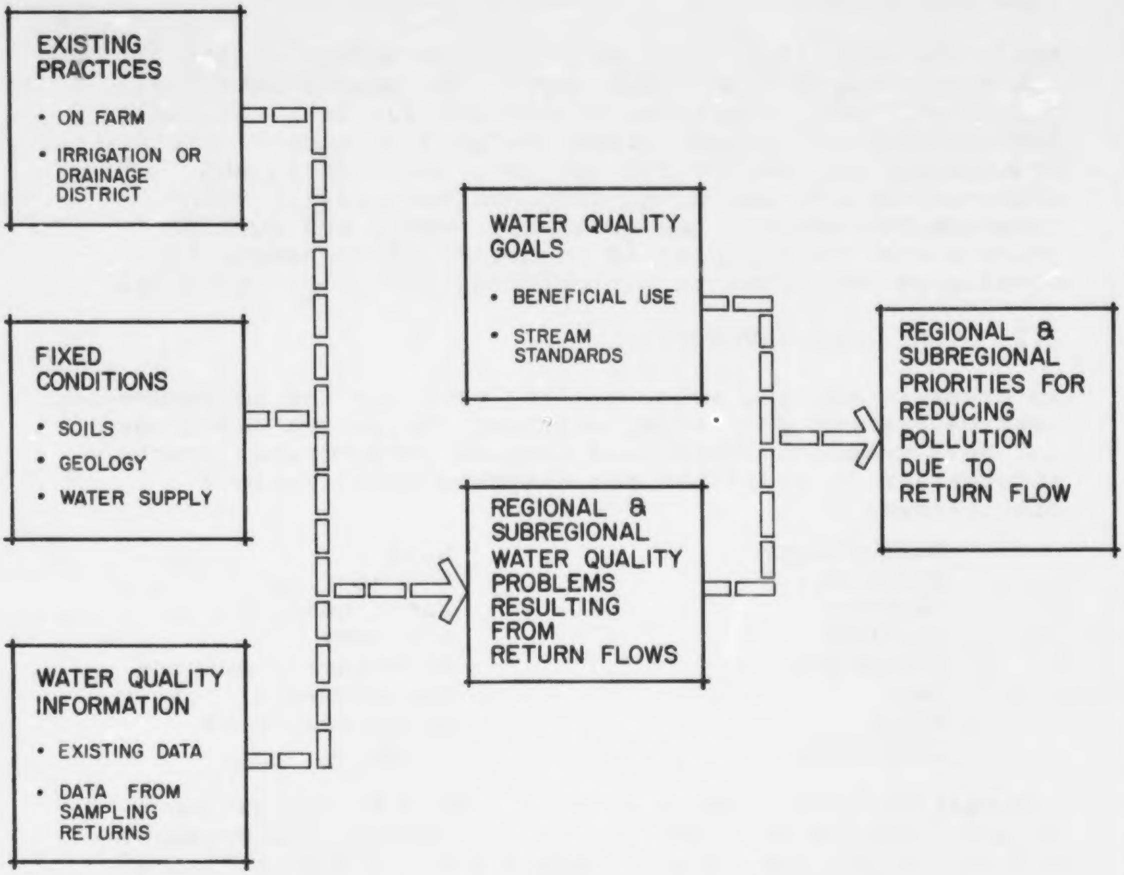

EXISTING PRACTICES
• ON FARM
• IRRIGATION OR DRAINAGE DISTRICT
FIXED CONDITIONS
• SOILS
• GEOLOGY
• WATER SUPPLY
WATER QUALITY INFORMATION
• EXISTING DATA
• DATA FROM SAMPLING RETURNS
WATER QUALITY GOALS
• BENEFICIAL USE
• STREAM STANDARDS
REGIONAL & SUBREGIONAL WATER QUALITY PROBLEMS RESULTING FROM RETURN FLOWS
REGIONAL & SUBREGIONAL PRIORITIES FOR REDUCING POLLUTION DUE TO RETURN FLOW

FIG 2-1. BMP MANUAL METHODOLOGY - IDENTIFICATION OF WATER QUALITY IMPACTS OF IRRIGATION RETURN FLOW

toups corporation
loveland, co.

In addition, the data should be collected at two levels: on-farm and sub-regional. Table 2-2 lists the types of information necessary for both levels. Generally speaking, on-farm data is much more specific and detailed than sub-regional data. The same type of information may be necessary at both levels, but in different degrees of detail.

Information relative to on-farm conditions and practices is available primarily through consultation with farmers themselves. The local Soil Conservation Service office can provide basic soils information. Flow data and water quality data will probably have to be collected by trained technicians and chemists, since farmers usually do not collect this information.

Sub-regional information will be found in practically each source listed in Table 2-1. Familiarity with the study area will indicate which are primary sources and which are secondary sources. The size of the study area and required detail will determine the sources.

2.2.1 Water Sources and Delivery Systems

Sources of irrigation water include groundwater and surface water. Locations and yields of wells and groundwater levels can be obtained from the U.S. Geoligical Survey (USGS) or state geological surveys. State agencies responsible for groundwater rights administration may have records of more recent wells.

The U.S. Bureau of Reclamation (USBR) supplies surface water to many areas and has records of deliveries from their projects.

Irrigation districts and conservancy districts have records available regarding storage, reservoir locations, capacities, etc. Locations and capacities of canals are also available. Many canal locations are indicated on USGS quad maps. State engineers' offices or state water resource agencies have additional information.

TABLE 2-1. SOURCES OF INFORMATION

Soil Conservation Service
Cooperative Extension Service
College Experiment Stations
Vocational Agricultural Service
U.S. Geological Survey
Equipment Dealers
Consulting Engineers
State Water Resource Agencies
State Water Quality Agencies
County Planning
Environmental Protection Agency
U.S. Department of Agriculture
State Departments of Agriculture
Regional Governmental Agencies
U.S. Department of Commerce (Census)
Agriculture Supply Dealers
National Weather Service
U.S. Bureau of Reclamation
County Health Departments
Farmers
Libraries
Irrigation Districts
County Agents
Universities
Farm Magazines
River Commissioners
State Water Research Institute (Land Grant College)
U.S. Corps of Engineers
Ditch Riders and Local Watermasters
Consulting Irrigation Engineers

TABLE 2-2. KINDS OF INFORMATION

On-Farm	Sub-Regional
Application method	Climate
Drainage system	Topography
Soil types	Irrigation districts
Soil intake rates	Conveyance systems
Field slopes	Geology
Labor costs	Hydrology
Crops	Storage reservoirs
Field shape	Aquifers
Water quality	Maintenance costs
Return flow	Drainge
Fertilizer use	Return flow
Pesticide use	Water quality
Maintenance costs	Water quantity
Water rights	Water rights
Flow data	

Irrigation districts and local ditch companies have cost data for construction and maintenance of reservoirs and canals. Miles of lined and unlined canals, flow measurement methods, irrigated acreages, plus delivery times and seasons, can also be obtained.

2.2.2 Water Quality and Quantity Information

Stream flow and water quality records are maintained by the U.S. Geological Survey as well as several other Federal and State agencies. Existing flow and quality data may well be the best source available in pinpointing irrigation return flow problems in an area. While it may provide a basis for problem identification, a more in-depth study leading to definition of specific local problems may require on-site sampling and flow measurement.

Most of the stations maintained by the USGS and other agencies have rather long periods of record and may be used to obtain information on averages and trends. Existing data can also provide an insight to the impact of irrigation return flows, but it cannot be substituted for an understanding of the conditions which bring about these changes in water quality and quantity.

Records for the major stations are published annually in the USGS publication Water Resources Data for (State) which is published in two parts--Part I, Surface Water Records, and Part II, Water Quality Records. Collection of this data is probably a first step in analyzing an area.

The Catalog of Information on Water Data, published by the U.S. Department of Interior, Geological Survey, Office of Water Data Coordination, contains a listing of all water data stations maintained by the USGS and other Federal and State agencies. This publication can be used to identify all data stations and their periods of record, as well as the types of data offered. The actual data is not included and must be found elsewhere. The catalog contains several volumes divided into river basins. It is available from: Office of Water Data Coordination, U.S. Geological Survey, National Center, Mail Stop 417, Reston, Virginia 22092.

STORET is another such water quality data file, maintained by the U.S. Environmental Protection Agency. Printouts of the data can be obtained through the EPA.

USGS and EPA water quality records are generally for larger streams and rivers in a state. State water quality agencies have on-going monitoring programs in most states. Some local agencies such as county health departments and designated 208 agencies also have water quality data.

The EPA and State water quality agencies have Section 303, Section 208, and Section 201 documents. These documents are Regional Water Quality Plans, Areawide Waste Treatment Plans, and Waste Treatment Facility Plans, respectively. Many of these plans have good water quality information.

2.2.3 Irrigation Methods

General knowledge of irrigation methods is necessary in evaluating problems associated with irrigation return flow. While statistics can be obtained from the U.S. Department of Commerce, Census of Agriculture, and from the various state departments of agriculture, these statistics are generally on a county-wide basis. Such statistics are useful in presenting general background information on an area, but do not give sufficient detail.

Local agricultural experts including extension personnel and Soil Conservation Service personnel are the best source of information regarding the irrigation methods predominately used within a region. When gathering information about irrigation systems, several items are important:

- Type of system
- Slopes of fields
- Water application rates
- Water intake rates of soils
- Shapes of fields
- Description of crops (consumptive use of water)
- Labor required (hours per acre per irrigation)
- Costs of system (capital, operation, and maintenance)
- Adaptable to fertilizer and pesticide use
- Irrigation season and scheduling

Irrigation costs which include capital costs, and operation and maintenance costs, are important to the irrigator if he is to change his system or adopt a new one. Cost and production information should include:

- Yield per acre
- Value of crop per unit
- Pumping costs (energy costs)
- Initial investment cost
- Labor costs - hours/irrigation
  irrigations/year
  costs/year/acre
- Depreciation costs
- System maintenance costs

The cost information is necessary to compare an existing irrigation system with a proposed system. If upgrading an existing system or converting to a new system is recommended for solving a return flow problem, implementation and operation and maintenance costs must be considered for determining cost-effectiveness and farmer acceptance.

2.2.4 Drainage Methods

In many areas, artificial drainage systems have been installed to prevent the water table from becoming too close to the surface. These systems are designed and installed on an individual farm basis, or through drainage districts. In many areas the Soil Conservation Service (SCS) designs these systems for farmers and, as a result, is a good source of information to locate subsurface drains. Drainage districts can provide similar information.

2.2.5 Irrigated Areas

The irrigated area in a region may be defined either through mapped data or through statistical data.

Statistical Data

Statistical data is readily available from either the Census of Agriculture, published by the U.S. Department of Commerce, or from various state departments of agriculture. This data is on a county-wide basis. For studies of agricultural return flows, it is desirable to have data on a basis of various sub-basins involved rather than by county. This data is not readily available as statistical data, but it can be obtained from mapped data.

Mapped Data

Mapped data is available from several sources at various levels of detail. The Soil Conservation Service has made county-wide land use maps for many areas. These maps have a scale of 1:126,720 (1/2-inch per mile). While these maps provide a good overall picture of the area, the level of detail may not be as high as desired. In areas undergoing irrigation development, the information may not be as up-to-date as is desired. Still, these maps provide the best readily available information on irrigated areas. These maps are generally available from local or state Soil Conservation Service offices, or from U.S. Department of Agriculture-Soil Conservation Service, Cartographic Unit, Western Regional Office, Portland, Oregon.

A higher level of detail is available from the aerial photographs (approximately 8 inches = 1 mile) which are maintained on file by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, and by the Soil Conservation Service. These aerial photographs provide the best information in locating the irrigated area. These photographs are not usually collated onto a larger map. Other aerial photography and remote sensing data is available from the U.S. Geological Survey and N.O.A.A. (Department of Commerce).

State and county land-use agencies represent another potential source of data for defining the irrigated area.

2.2.6 Climatic Conditions

This information is readily available from the National Weather Service, U.S. Department of Commerce. Length of growing season, annual precipitation, and wind information are necessary for analysis.

2.2.7 Soils Data

Soils data is available from the U.S. Department of Agriculture Soil Conservation Service. In most irrigated regions, this data is quite comprehensive and may be obtained in various levels of detail. In most cases, the general soil associations will provide sufficient detail for problem definition. Relevant soil characteristics include permeability, depth to impermeable layers, and any chemical characteristics which might be responsible for the impairment of water quality, such as high sodium or salinity content.

2.2.8 Geologic Data

Geologic data is available from either the U.S. Geological Survey or the Geological Survey of the various states. The analysis of geologic data would be limited to identifying bedrock and identifying the impact that these bedrock formations might have on water quality. Where well development is significant, it is important to identify aquifers, the quality of water in individual aquifers, and uses of the water in the aquifers.

2.2.9 Chemical Use

Fertilizer

Fertilizer-use data may be difficult to find on a detailed basis. On the regional basis, soils labs, fertilizer dealers and extension agents may recommend application rates and timing to farmers for various crops. Such data does not verify actual practices, however. Some interviews with farm operators are necessary to obtain information on actual fertilizer use.

Pesticides

As with fertilizer data, pesticide use data can be difficult to obtain. Consultation with dealers, crop dusters, extension agents and others can probably provide the best information.

2.3 PROBLEM DEFINITION

Problem areas are areas with common conditions of agricultural practices, soils, and other factors which share common pollutant problems. A data collection and analysis program such as discussed here and in Chapter 4.0 will provide the tools for problem definition. Figures 4-7 and 4-8 display analysis leading to problem area definition.

The key to problem area definition is to have a base map of the irrigated area with transparent overlays displaying soils, geology, and water quality data. Water supply information and other data may also be of value. The information thus organized can be used to compare existing water quality with water quality goals. Information gained on the irrigation system can then be used to assess the water quality (and quantity) limitations necessitated by irrigation, as well as avoidable water quality limitations.

The accumulated information may then be used to develop priorities. Priorities may develop naturally, or may be established through matrix analysis. Evaluation criteria stem from national, regional, and on-farm goals.

3.0 DEFINITION OF BEST MANAGEMENT PRACTICES FOR IRRIGATED AGRICULTURE

The term "best management practices" (BMP) means a practice, or combination of practices, that is determined by a State (or designated areawide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals. (40 CFS Part 130)

In order to select the best management practices, control options must be compared. Suggested comparison criteria are:

- Costs
- On-farm benefits
- Effectiveness in improving water quality
- Legal constraints
- Institutional constraints
- Social acceptability

Costs, benefits, and effectiveness are important, and this manual is directed towards evaluation on this basis. Nevertheless, the remaining criteria cannot be overlooked. Figure 3-1 shows the processes leading to definition of best management practices.

In most cases, a control option is either legally acceptable or it violates existing laws. If legal constraints impose too great an obstacle for implementation, other options should be evaluated. Water allocation laws and water quality laws that have built-in hindrances to BMP implementation are examples of legal constraints.

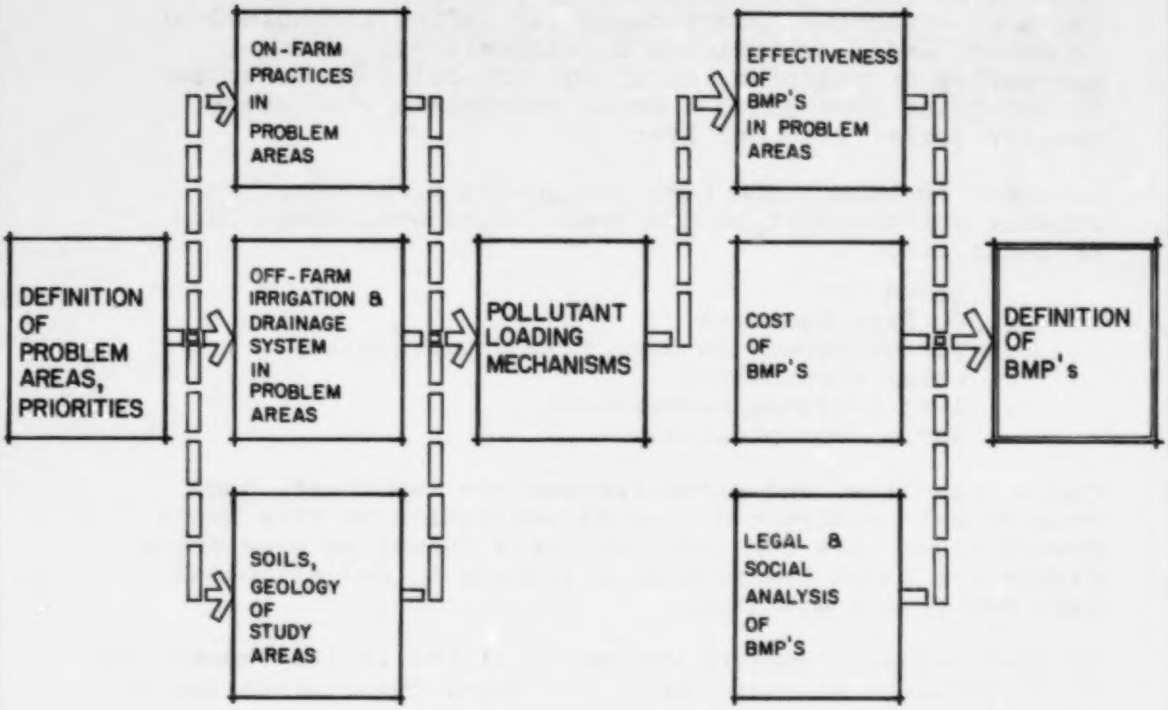

DEFINITION OF PROBLEM AREAS, PRIORITIES
ON-FARM PRACTICES IN PROBLEM AREAS
OFF-FARM IRRIGATION & DRAINAGE SYSTEM IN PROBLEM AREAS
SOILS, GEOLOGY OF STUDY AREAS
POLLUTANT LOADING MECHANISMS
EFFECTIVENESS OF BMP'S IN PROBLEM AREAS
COST OF BMP'S
LEGAL & SOCIAL ANALYSIS OF BMP'S
DEFINITION OF BMP's

FIG. 3-1. BMP MANUAL METHODOLOGY - DEFINITION OF BEST MANAGEMENT PRACTICES

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Once it is determined that there are no significant legal barriers, the options can be compared based on costs, benefits, effectiveness, and institutional constraints. Costs can usually be assigned dollar values and include capital costs, operational costs, and labor costs. Benefits include improved water quality, increased crop yields, conservation of water, and others.

Institutional constraints are factors which impede timely implementation. Permits may be required, water rights transferred, or variances obtained.

3.1 SUB-REGIONAL VS. ON-FARM EVALUATION

This manual recognizes two levels of best management practices evaluation: sub-regional and on-farm. The purpose of sub-regional evaluation is to provide guidelines and technical data which can be used for on-farm evaluation and which are in accordance with recognized goals. The purpose of on-farm evaluation is to select best management practices which have been determined to be effective in sub-regional analysis and are suitable to the particular farming situation.

The sub-regional evaluation should then result in:

- Definition of problem areas
- Definition of best management practices and guidelines for their use.

Intermediate data generated in the process of developing a sub-regional plan forms the basis for on-farm evaluation. This information includes:

- Information on practices and natural conditions contributing to excess pollutant load in problem areas.
- Information on effectiveness of control options in light of practices and natural conditions.
- Cost data to be used in evaluation of BMP's.

The sub-regional analysis may thus provide the guidelines for the field technician to use in suggesting best management practices to the farmer. It is anticipated that this can be conducted in much the same manner as soil conservation plans are currently developed by the Soil Conservation Service.

3.2 DEFINITION OF POLLUTANT PATHWAYS

An irrigation return flow system may be very complex for a problem area. Numerous irrigation practices and environmental conditions can result in increased pollutant levels for each parameter through all five return flow paths (Figure 3-2).

Table 3-1 summarizes factors which contribute to pollutant loading. The potential for certain pollutant loadings exists because of the type of irrigation practice, i.e., the potential for sediment pollution always exists when there is surface irrigation on steep slopes, but not when subsurface irrigation is practiced.

Each pollutant can be associated with certain return flows. If salinity problems exist, the primary return flow mechanism would be deep percolation. Tailwater and bypass water would not be applicable. Table 3-2 associates the common pollutants with possible loading mechanisms. Pollutant information is detailed in Chapter 5.0.

3.2.1 Quantification of Pollutant Loading Mechanisms

Figure 3-3 shows an example of how several existing practices can be related to one pollutant or how one practice can cause more than one pollution problem.

Before control options can be evaluated, these pollutant pathways must be quantified. This process may require:

- Irrigation efficiency studies
- Conveyance efficiency studies
- Return flow quality determination.

Since loading processes for each pollutant are different, it is necessary to consider the pollutants separately.

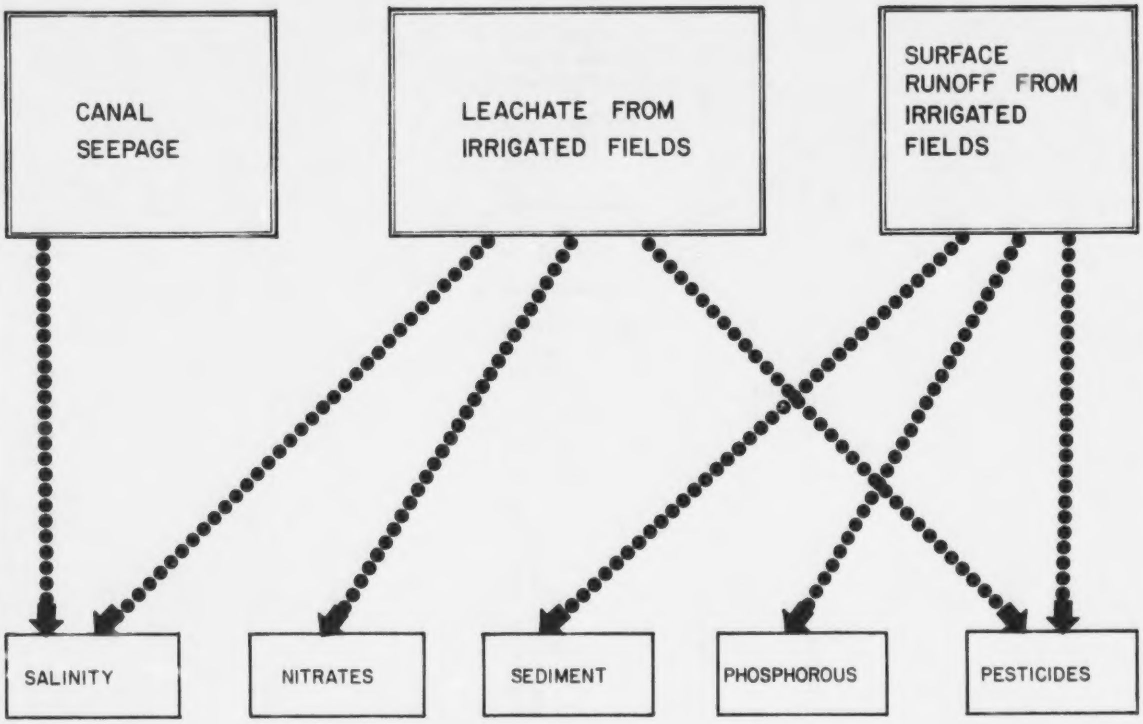
CANAL SEEPAGE
LEACHATE FROM IRRIGATED FIELDS
SURFACE RUNOFF FROM IRRIGATED FIELDS
SALINITY
NITRATES
SEDIMENT
PHOSPHOROUS
PESTICIDES

FIG. 3-2. MAJOR POLLUTANT PATHWAYS

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TABLE 3-1. SUMMARY OF FACTORS CONTRIBUTING TO POLLUTANT LOADING

	SOILS		TOPOGRAPHY		GEOLOGY		IRRIGATION METHOD			WATER SUPPLY			LAND USE		FERTILIZER USE		IRRIGATION EFFICIENCY		
	SOILS		TOPOGRAPHY		GEOLOGY														
	Heavy (fine)	Light (sandy)	Steep	Flat	Non-saline Formation	Saline Formation	Sprinkler	Furrow (row crop)	Border (close growing crop)	Groundwater	Lined Ditch	Unlined Ditch	Significant seep areas & Phreatophytes	Little seep area & Phreatophyte prob.	Heavy Nitrate Use	Low Nitrate Use	High	Low (Excessive Deep seep)	Low (Excessive Tailwater)
Salinity						X						X	X					X	
Nitrates		X													X			X	
Sediment	X		X					X				X							X
Phosphorous	X		X					X	X										X

TABLE 3-2. LOADING MECHANISMS FOR POLLUTANTS ASSOCIATED WITH IRRIGATION RETURN FLOW

Pollutant	Associated With Surface Runoff (Tailwater)	Associated With Leachate From Irrigated Fields (Deep Percolation or Artificial Damage)	Associated With Canal Seepage	Associated With Bypass Water
Salinity		X	X(2)	
Nitrates		X		X(3)
Sediment	X			X
Phosphorous	X			
Pesticides	X(1)	X(1)		

(1) Loading mechanism varies with characteristics of particular pesticide.

(2) Only when contributing to groundwater which becomes consumptively used in wet areas or where saline subsoils exist.

(3) Primarily where nitrogen is applied with irrigation water.

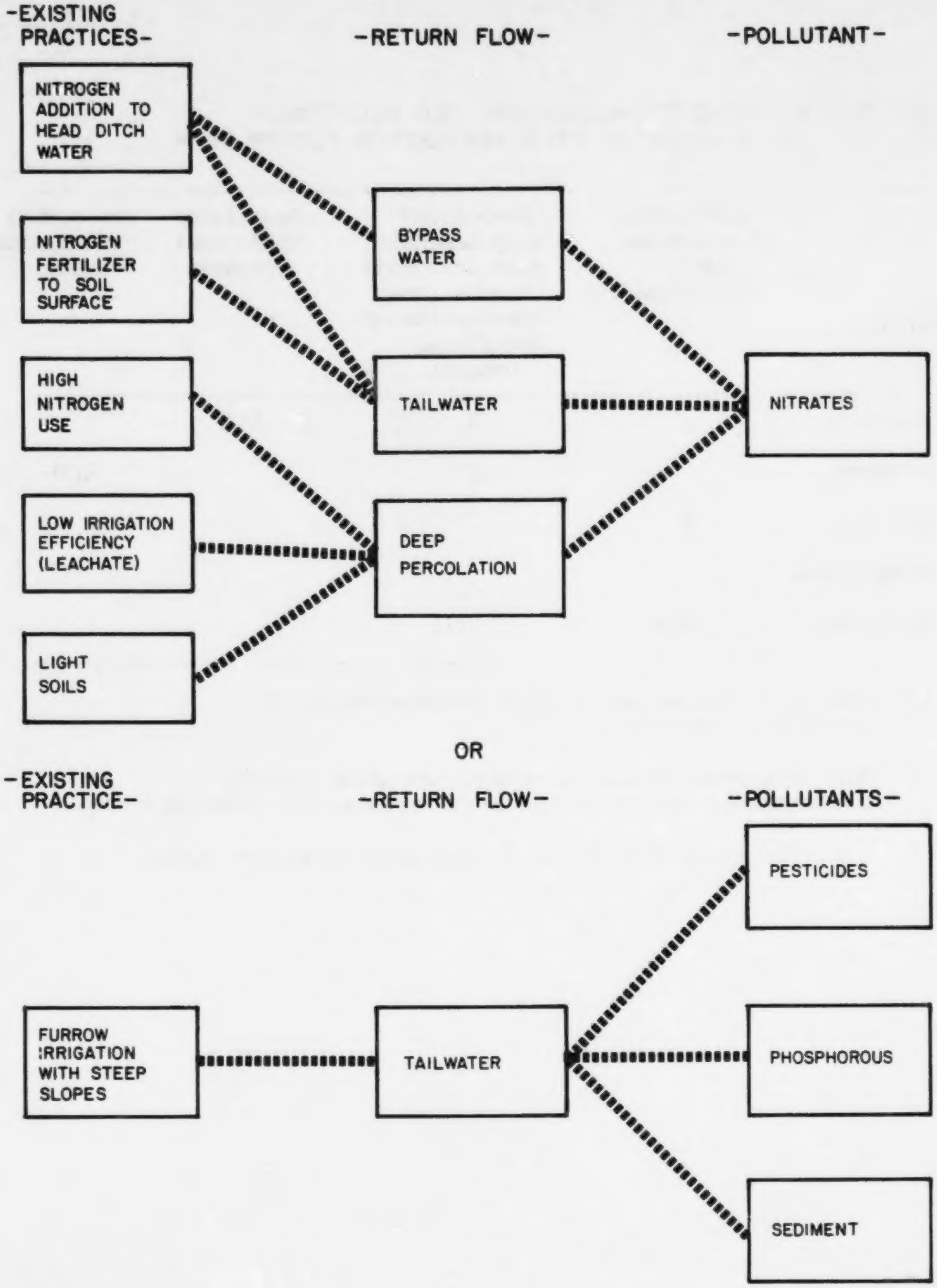
-EXISTING PRACTICES-
-RETURN FLOW-
-POLLUTANT-
NITROGEN ADDITION TO HEAD DITCH WATER
NITROGEN FERTILIZER TO SOIL SURFACE
HIGH NITROGEN USE
LOW IRRIGATION EFFICIENCY (LEACHATE)
LIGHT SOILS
BYPASS WATER
TAILWATER
DEEP PERCOLATION
NITRATES
OR
-EXISTING PRACTICE-
-RETURN FLOW-
-POLLUTANTS-
FURROW IRRIGATION WITH STEEP SLOPES
TAILWATER
PESTICIDES
PHOSPHOROUS
SEDIMENT

FIG. 3-3. EXAMPLES OF INTERRELATIONSHIPS

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Salinity

In all irrigated areas, the primary cause of increased salinity is concentration through consumptive use. In most areas, this is the only significant cause of higher salinity levels. In such cases, the total salt load, expressed in tons, is not increased through the system.

Where salt concentrations are increased only through cropland consumptive use, little potential for improvement exists. What potential does exist will have to be determined through greater study of the effect of leaching fraction on salt load under local soil and water conditions.

In a few irrigated areas, however, salinity problems may be added to by non-beneficial consumptive use or by dissolving salts (pickup) from saline subsoils. In such cases, attempts should be made to quantify the pollutant load resulting from conveyance systems, excess leaching of irrigated land and evaporation and phreatophyte use. Determination of the quantity of water taking each pathway first requires a system inventory of the problem area. Quantities which should be determined or estimated are:

- Length of major canals in problem area
- Length of laterals in problem area
- Length of on-farm head ditches in the problem area
- Irrigated acreage in the problem area.

In order to arrive at a common denomination for control option evaluation, it is desirable to express canal length as the amount needed to service a unit of irrigated land. Thus, if 10 miles of laterals serve 6,000 acres, there are .0016 miles of canal per irrigated acre. Costs of improvements per mile can be converted to per acre cost in this manner.

Determination of the resulting pollutant load requires knowledge of the quality of these waters, as well as of the quantity. These quality changes must be observed through intensive research and sampling programs.

Nitrates

Nitrate loading results primarily through leaching of irrigated soils. Soils where nitrate problems exist tend to be light and well drained, factors which make it easy to apply excessive water. Control options which reduce excessive leaching may generally be evaluated in terms of a proportional decrease in nitrate loading. Those control options which do not reduce leaching but alter fertilizer practice are much more difficult to evaluate, requiring experimental evaluation.

The effectiveness of nitrate control options is highly dependent upon soil conditions. As a result the loading of nitrates as a function of fertilization has produced mixed results (see Chapter 4.0).

Sediment, Phosphorus, and Sediment Associated Pesticides

Tailwater is the primary loading mechanism for these pollutants. Those control options which reduce tailwater volume can be expected to reduce loading of these pollutants by at least an equal percentage. Reductions by a greater percentage is possible since runoff stream velocities are generally reduced. Sediment ponds, filter strips and grassed waterways have a wide range of effects depending upon local conditions. These are discussed in Chapter 4.0.

3.3 CONTROL OPTION EFFECTIVENESS EVALUATION

Since it may not be possible to implement every control option, the following questions should be addressed:

1. What percentages of the total pollutant loading can be attributed to pollution caused by irrigated agriculture?

2. How can the pollutants be ranked in terms of their impact on beneficial use or seriousness of water quality degradation?
3. What percentage reduction of each pollutant can be attained by each control option?
4. Which options can result in the most benefits (greatest reduction in pollution) for the least dollars spent?

The effectiveness of control options in meeting water quality goals can be compared in a similar manner for one field or for the sub-basin. Effectiveness should be evaluated in terms of the importance of a particular pollutant and the potential for reduction of that pollutant. Such analysis should be conducted for each prospective control option. Each control option is discussed in Chapter 5.0 in terms of applicability and effectiveness.

3.3.1 Control Option Effectiveness Determination

Control options can be compared in terms of their potential reduction in pollutant loading. Table 3-3 displays an example of an analysis of the effectiveness of control options. This type of evaluation requires a considerable knowledge of the changes which are likely to occur upon implementation of BMP's. Development of this information must be conducted at the sub-regional level due to the level of technical information required.

The effectiveness of control options is a result not only of the change in hydraulic loading, but also of the change in quality. The change in hydraulic loading is fairly easy to identify. The change in the quality of return flows is not so easy to identify and will likely require a research effort, especially for salinity.

In Table 3-3 we see the various parameters which need to be identified. In this example, the estimated subsurface return flow volume is 1000 acre-feet over a specified area. Of this 1000 acre-feet, canals, laterals and on-farm ditches each contribute 100 acre-feet. Leaching of irrigated fields contributes 70 percent of the total load to groundwater, or 700 acre-feet. These estimates can be made from irrigation efficiency studies, and from conveyance efficiency studies.

The reduction in hydraulic load resulting from each control option (column 3) can be estimated with a fair degree of accuracy, based upon comparison of existing efficiencies with projected improved efficiencies resulting from application of best management practices. In this example, it is assumed that furrow irrigation is used, and that the average leaching volume is 0.4 acre-ft/acre. It is estimated that sprinkler irrigation without irrigation scheduling could safely reduce this to 0.3 acre-ft/acre, a 25 percent reduction (column 3).

The area is served by a canal which supplies 500 mg/l TDS water. This is relatively constant through the system. Samples from the groundwater directly below the canals indicate that the seepage water has increased to 700 mg/l as a result of phreatophyte use or salt pickup (column 5).

The quality of return flows resulting from leaching of croplands has been found to be about 2000 mg/l TDS. It is not expected that irrigation scheduling will change the leaching fraction sufficiently to change this quality. Sprinkler irrigation is expected to reduce the leaching fraction sufficiently to increase the concentration to 200 mg/l. Total loading (quantity x quality) would be less, however.

It is in determining the quality of return flows that significant uncertainties come into the picture. It is quite difficult to assess the quality of returns under existing conditions, and very difficult to predict the quality of returns under other leaching conditions. Uncertainties are had in knowing what exactly is being sampled, hydrologic variations, and variations in human input. Research at the sub-regional level will probably be required in order to obtain figures which have validity.

TABLE 3-3 CONTROL OPTION EFFECTIVENESS COMPARISON - EXAMPLE: SALINITY

Practice	1 Total Subsurface Return Flow Volume - Ac-Ft (Existing Condition)	2 Fraction of Total Hydraulic Loading Contributed By This System	3 Reduction In Hydraulic Load With Control Option (Fraction)	4 Quality of Input Water mg/l TDS	5 Quality of Return Flow Existing Practice mg/l TDS	6 Quality of Return Flow With Control Option mg/l TDS	7 Salt Load Existing Practice (Tons)	8 Salt Load With Control Option (Tons)	9 % Reduction In Load
CONVEYANCE SYSTEM IMPROVEMENT									
Canal Line	1,000	.10	.9	500	700	700	95	71	1
Lateral Line	1,000	.10	.9	500	700	700	95	71	1
Ditch Line	1,000	.10	.9	500	700	700	95	71	1
IN-FIELD PRACTICES									
Irrigation Scheduling	1,000	.70	.1	500	2,000	2,000	1,904	1,761	6
Sprinklers	1,000	.70	.25	500	2,000	2,100	1,904	1,618	13
Sprinklers With Scheduling	1,000	.70	.30	500	2,000	2,100	1,904	1,542	16
Level Basin	1,000	.70	.25	500	2,000	2,100	1,904	1,618	13
Level Basin With Scheduling	1,000	.70	.30	500	2,000	2,100	1,904	1,542	16

Column 7 = Column 1 (ac-ft) x Column 2 x Column 5 (mg/l) x 1.36 x 10^{-3} = Tons

Column 8 = Column 1 (ac-ft) x Column 2 x (1 - Column 3) x Column 6 x 1.36 x 10^{-3} + Column 1 x Column 2 x Column 3 X Column 4 x 1.36 x 10^{-3} = Column 1 (ac-ft) x Column 2 x 1.36 x 10^{-3} [(1-Column 3) x Column 6 + Column 3 x Column 4)] = Tons

Column 9 = $\frac{\text{Column 7 - Column 8}}{\text{Total Sale Load (all sources)}}$. Here total salt load = 95 canals + 95 laterals + 95 ditches + 1,904 field leaching = 2,189

For salinity, it is recommended that guarded pessimism be used in predicting reduction in pollutant load. Improved irrigation practices can be effective in reducing total salt load, yet any significant reduction in leaching fraction (hydraulic loading) can be expected to result in an increase in salinity of the leachate. This increased concentration may be accompanied by an undesireable change in the ionic composition of the water, due to precipitation of less soluble ions in the soil.

Practices for control of nitrates can be evaluated in much the same manner as displayed in Table 3-3. Nitrate analysis is much easier, since the concentration of nitrates in the leachate is less influenced by leaching fraction. Prediction of results obtained by altered fertilizer practices may be more difficult.

Sediment and phosphorous control practices may be evaluated by similar procedures.

3.3.2 Effectiveness in Meeting Regional Goals

Regional goals may be the result of in-stream water quality or downstream water uses. Definition of these conditions will aid in the definition of water quality goals. The potential for improvement may then be considered based upon pollutant source and potential for reduction in pollutant loading.

The program for irrigated agriculture should be defined so that the selected best management practices are effective towards meeting water quality goals. Some goals may be achieved, and other water quality problems may not be significantly reduced even with a high level of effort. Salinity is generally an example of where a high degree of effort may result in only marginal improvement.

The existance of several goals for pollutant loading reduction from irrigation returns may make best management practices which are effective for more than one pollutant highly desireable. Also, the existance of several goals may require that a level of effort for each of the several goals be defined.

3.3.3 Determination of Sub-Regional Best Management Practices

Sub-regional best management practices must also be evaluated in terms of cost-effective, institutional, social, and legal constraints. The cost-effectiveness of sub-regional best management practices can be evaluated using an objective analysis. While most best management practices will have to be tailored to specific farming situations, a sub-regional analysis identifies those practices effective in meeting water quality goals in a region.

A sub-regional analysis is displayed in Table 3-4. In this table, acreage recommendations and estimated participation are included so that regional costs can be estimated. The computed cost is a function of these participation levels. As a result, the effectiveness-cost ratio is independent of participation levels and recommended acreages.

The effectiveness cost ratio and ranking can be computed either as a function of the ratio of effectiveness to total cost or as the ratio of effectiveness to costs in excess of non-water quality benefits (net cost attributable to water quality). Decision of priorities then requires some subjective decisions. Alternatives which appear good in some ways may be discounted due to legal, institutional, or social constraints or possibly due to energy requirements.

3.3.4 Estimation of Reduction in Pollutant Loading

By combining the expected result from each installation of a practice (Section 3.3.1) with the expected participation levels developed for Table 3-4, it is possible to estimate the reduction in the loadings of a particular pollutant. This represents an areawide quantity, and does not represent the change in load on the receiving waters. Nutrients and sediment are non-conservative, and re-use of the results in a reduction in loading. Prediction of improvement of in-stream quality must account for these factors as well as total loading.

TABLE 3-4. RANKING OF SUB-BASIN ALTERNATIVES AND COST ESTIMATION

(1) Control Option	(2) Effectiveness in Meeting Regional Goals	(3) Percent of Irrigated Acreage for which practice is recommended (or % of Ditch length) (percent)	(4) Estimated Participation at prescribed level of cost sharing (percent)	(5) Combined Effectiveness	(6) Equivalent Annual cost at expected level of Implementation (thousands)	(7) Direct Annual Benefits (thousands)	(8) Effectiveness Cost Ratio		(9) Rank	
							$\frac{E}{C}$ X10-6	$\frac{E}{C-B}$ X10-6	$\frac{E}{C}$	$\frac{E}{C-B}$
A	1.159	50	20	.0159	20	10	.795	1.59	3	4
B	0.20	60	50	.06	40	5	1.5	1.7	2	3
C	0.10	70	90	.063	30	10	2.1	3.15	1	1
D	0.05	30	40	.006	10	8	0.6	3.0	4	2

TOTAL COST OF PROGRAM ____________________

NOTES:

(Column 1) - All options can be compared regardless of the subsystem problem they address.

(Column 5) - Product of Columns 2, 3, and 4.

(Column 6) - Unit cost x total acreage x Column 3 x Column 4. Total length of ditch may be substituted for total acreage.

(Column 7) - Direct annual benefits other than water quality including:
- o Reduced operational expense
- o Increased crop yields

Water savings may or may not be accounted for as benefit.

(Column 8) - The effectiveness-cost ratio may be determined using either the total cost or the cost not directly attributable to other benefits, i.e., $\frac{\text{Column 5}}{\text{Column 6}}$ or $\frac{\text{Column 5}}{\text{Column 6 or Column 7}}$

(Column 9) - Alternative ranking may be done by either of the above methods.

3.3.5 Determination of On-Farm Best Management Practices

It is recommended that best management practices for a particular farm be evaluated in terms of their effectiveness in meeting water quality goals in relation to their net cost. This evaluation procedure is geared to a voluntary program where cost-sharing is used as an incentive. Legal, institutional, and social constraints must be taken into account when evaluating on-farm improvements.

The farmer or landowner, when evaluating an improved practice, wants to make the benefits exceed his costs. That is:

$$B > CA$$

Where B = Annual dollar benefit of increased yield, and decreased operational expense.

CA = Equivalent annual cost to the farmer.

Specific costs associated with control options are discussed in Chapter 5.0. Implementation of BMP's on a voluntary basis can only be expected when net benefit to the farmer can be demonstrated.

Benefits to the nation occur as improved water quality and better utilization of water resources. Assignment of dollar values to these parameters is possible, but often difficult and inaccurate. Money spent for pollution control should achieve a high degree of effectiveness per tax dollar, or:

$$\frac{E}{Cp}$$

Should be large compared to other alternatives. Where

E = Comparitive effectiveness in meeting regional water quality goals.

Cp = Equivalent annual cost to the public.

3.4 CASE STUDY - BEST MANAGEMENT PRACTICES FOR IRRIGATED AGRICULTURE IN THE LARIMER-WELD REGION OF COLORADO

Much of the methodology presented in this manual is the result of work conducted by the consultant in developing a BMP plan for the Larimer-Weld Regional Council of Governments (LWRCOG). Toups Corporation conducted this work under two separate contracts. The first contract, initiated in the summer of 1976, was a result of the water quality planning program being conducted by the LWRCOG under Section 208 of P.L. 92-500. This contract resulted in the report, "Water Quality Impacts of Irrigation Return Flow in the Larimer-Weld Region." A second contract awarded Section 104-b funds to the LWRCOG in order to define "Best Management Practices," including social, institutional, and financial roles for the region. This section contains a brief review of the experiences of the consultant in carrying out these contracts.

3.4.1 Water Quality Impacts of Irrigated Agriculture

Analysis of the Water Quality Impacts of Irrigated Agriculture in the region consisted of:

- Analysis of irrigation practices;
- Hydrologic analysis;
- Water quality analysis of discharges and receiving waters;
- Analysis of water quality problems associated with irrigation return flows.

The analysis of irrigation practices consisted of collecting data from several sources. Soils data, geologic data, and data on the irrigated area and canal system were all mapped. Information on fertilizer and pesticide use was collected through interviews with farmers, crop-dusters, and others.

The area consists of approximately 500,000 irrigated acres, with surface water being the principal water source. Surface irrigation is used on over 90 percent of the irrigated land.

Hydrologic analysis consisted of gathering data on the location and amount of returns and diversions. Major surface drains entering the river were measured and quality samples taken. Groundwater inflows to the rivers were quantified through inflow-outflow analyses. The maintenance of records of surface water diversions by the State Engineer allowed flow routing through the river system. Irrigation diversions dry up rivers throughout the region, in the summer for irrigation and in the winter for storage.

Water quality analysis consisted of taking samples of rivers, drains, and other discharges. Approximately 150 sampling sites were utilized with flow measurements incorporated at each. In this way, the water quality sampling program was tied to the hydrologic analysis. The water quality sampling pointed to specific problems in the region which could be typified by soils, geology, irrigation method and other agricultural practices.

Data obtained on soils, geology, hydrology, water quality, and practices was mapped and displayed graphically in a method similar to that displayed in Section 4.2 of this document. Conclusions from this analysis were:

> Hydrologic impacts of irrigation are the major impediment to water quality. Streams in the irrigated portion of the region are repeatedly dried up by diversions. Below these points, irrigation return flow is the only source of water to the region.

- Areas which were shallow to certain cretacious formations were found to have highly saline groundwater (E.C. greater than 5000 umho/cm) despite good quality supply water (EC less than 500 umho/cm). Problems resulting from contact of irrigation seepage water with the saline groundwater were high salinity in subsurface drainage returns and numerous salt seep areas (high water tables).

- Concentrated cattle feeding operations in the Greeley area resulted in enormous manure output. Transport expenses resulted in most of this manure being used within 7 miles of the source. Typical fertilizer practice in this area was 15 to 20 tons of manure/acre each year plus 150 pounds of N applied as chemical fertilizer plus about 50 pounds of N applied as anhydrous ammonia in the irrigation water. Soils were generally sandy loam. High nitrates were observed in subsurface drain discharges in this area.

- Sediment problems were especially pronounced along one of the smaller rivers, the Little Thompson. Here, cultivation and surface irrigation were practiced right up to the river banks. Sediment problems in other areas were much less due to interception of returns by lower ditches, and the existance of a non-irrigated flood plain.

3.4.2 Best Management Practices - Pollutant Loading Mechanisms

The Best Management Practices program consisted of an in-depth analysis of practices contributing to the identified problems as well as an analysis of options which could reduce the pollutant load.

Irrigation efficiency and water quality determinations were made with each irrigation on four study farms. Two of the farms were studied for salinity - one for nitrates and one for sediment. Flows both onto and off of the field were measured and sampled. Observation wells and soil moisture extractors allowed the sampling of groundwater and soil moisture. Canal seepage determinations were also made. The information gained in the program allowed quantification of pollutant loading mechanisms. Mechanisms for salinity and nitrates were:

- In areas with salinity problems, salt concentrations in leachate from the root zone were much lower than concentrations in the groundwater. Groundwater concentrations were the result of precipitated salt, weathering of parent shales, and non-beneficial consumptive use where high water tables existed. Excess water use was not a problem due to limited supply, but distribution efficiencies (coefficient of uniformity) were hampered by excessive or irregular slope.

  Since all waters entering the groundwater became part of the saline groundwater, it was determined that the problem could best be reduced by reducing the non-beneficial loss of surface water to groundwater.

- Underestimation of the nitrogen value was combined with poor irrigation efficiencies on sandy soil caused by excessive length of run. Leachate contained an average of 50 mg/l of $NO_3 + NO_2$ as N on one field.

Best Management Practices were evaluated for their cost and their ability to reduce the pollutant load. The mechanics of this analysis follow.

3.4.3 Cost Effectiveness for BMP's in Larimer-Weld Region

There are eight basic Best Management Practices which have been evaluated as to their pollutant reduction and cost effectiveness. These BMP's have been implemented to varying degrees in the Larimer-Weld Region for water conservation and labor saving reasons. They are also effective in reducing pollutant loadings.

Conveyance system improvements consist of converting earthen-lined head ditches, laterals, and canals to either concrete lined structures or pipelines. This has the effect of reducing seepage losses by 90 percent and erosion problems of 100 percent. By reducing seepage, the flow of groundwater across subsurface shales is reduced, thereby reducing salt pickup by the groundwater which ultimately finds its way to surface waters. Also, preventing seepage conserves water making it available as a dilutent in surface waters. This control option is valid only in areas with subsoil salinity problems or many seep spots.

Sprinkler irrigation systems have long been used in conjunction with groundwater supplies. They have proven to be more efficient than surface systems. Technology now exists to convert surface systems to sprinkler systems; being more efficient, less excess leaching and surface runoff occurs. By decreasing field leaching, salinity and nitrate loading are decreased and by reducing field runoff, sediment, phosphorous, and pesticide loading are reduced.

Water management improvements include irrigation scheduling, water measurement devices, and irrigator education programs. Each must be practiced before more efficient irrigation can be realized. Increased application efficiencies can minimize excess leaching (deep percolation losses) and field runoff (tailwater).

System efficiency improvements include such practices as cut-back furrow irrigation, shortening length of runs, and modifying field layout and furrow directions. These improvements can also increase irrigation application efficiencies.

Tailwater control practices reduce field runoff - sediment loss (loading), phosphorus, and pesticide pollution. Since phosphorus and most pesticides are transported with sediment, sediment control will solve these problems as well. Four methods were included in the analysis: 1) sediment ponds; 2) tailwater recycling; 3) buffer/filter strips; 4) grassed waterways.

Fertilizer management consists of using slow release nitrogen fertilizers and/or applying fertilizer at times when it can be used by the crop. The goal is to reduce nitrate loss through leaching to groundwater. Less amounts of fertilizer could be used or higher crop densities could be attainable.

Land leveling is a practice which can eliminate "seep holes", decrease slopes, or otherwise make possible more uniform irrigation in furrow or flood systems. This can reduce excess leaching and tailwater loss.

Drainage systems can lower groundwater tables and serve as collection drains for salt and nitrate laden seepage water. Lowering water tables helps keep land in production and collection of seepage water reduces water available for salt pick-up for transporting nitrates to groundwater supplies.

Table 3-5 summarizes the relationship between control options and pollutants for the Larimer-Weld region. This table contains regional input, since recognized problems are incorporated. As an example, conveyance systems were considered to be effective for salinity control within certain portions of this region, but they are not universally effective.

TABLE 3-5. POLLUTANTS AFFECTED BY BMP'S

				POLLUTANT		
	BEST MANAGEMENT PRACTICE	Salinity	Nitrates	Sediment (1)	Phosphorus (1)	Pesticides (1)
1	Conveyance System Improvement					
	Ditch lining or pipeline	CS(2)		CE(3)		
	Lateral lining or pipeline	CS		CE		
	Canal Lining	CS		CE		
2	Convert to sprinklers	FL(4)	FL	FR(5)	FR	FR
	Sprinklers with water management	FL	FL	FR	FR	FR
3	Water Management	FL	FL	FR	FR	FR
	Irrigation scheduling					
	Water measurement devices					
	Education programs					
4	System Efficiency improvements	FL	FL	FR	FR	FR
5	Tailwater Control					
	Sediment ponds			FR	FR	FR
	T.W. recycling			FR	FR	FR
	Buffer/filter strip			FR	FR	FR
	Grassed waterways			FR	FR	FR
6	Fertilizer Management (Slow release nitrogen)		FL			
7	Land Leveling	FL	FL	FR	FR	FR
8	Drainage Systems	FL	FL			

(1) Best Management practices which control sediment loading, also control phosphorus and pesticide loading.
(2) CS - Conveyance Seepage
(3) CE - Conveyance Erosion
(4) FL - Field Leaching
(5) FR - Field Runoff

BMP's have different effectiveness factors for reducing loading of salinity, nitrates, and sediment. In the analysis for the Larimer-Weld region, effectiveness for salinity control was measured as the effectiveness in reducing unnecessary water loss to the highly saline groundwater which existed in certain areas. In other areas, it was felt that salinity control measures would not be effective.

Sprinkler systems with water management can reduce water loss to the groundwater by about 25 percent (0.245 effectiveness factor). Sprinkler systems without water management and surface systems with water management can reduce loading by about 20 percent (0.210 effectiveness factor).

For nitrate loading, sprinklers with water management are most effective (35 percent and 0.350), with sprinkler systems without water management, surface systems with water management, and fertilizer management all reducing loading by 30 percent (0.300 effectiveness).

Since sediment pollution is more easily controlled, several BMP's have high effectivness factors:

Sprinkler Systems	85% reduction	0.855
Sediment Ponds	63% reduction	0.630
Tailwater Recycling	63% reduction	0.630

Table 3-6 shows the development of effectiveness factors. They have been developed as the product of the proportion of pollutant load contributed by a system (conveyance, field leaching, etc.) times the percent reduction in pollutant load from that system.

The proportion of pollutant loading was developed through study of both irrigation and conveyance efficiencies. This data was combined with data on irrigated acreage and total length of canals and laterals. In this way the relative contribution of field leaching and conveyance seepage could be determined.

TABLE 3-6. LOADING-REDUCTION EFFECTIVENESS FACTORS

BEST MANAGEMENT PRACTICES	REDUCTION IN CONVEYANCE SEEPAGE OR FIELD LEACHING FOR SALINITY CONTROL			NITRATES Field Leaching			SEDIMENT Field Runoff		
	Percentage Total Loading (1)	Percentage Reduction (2)	Effective Factor (3)	Percentage Total Loading	Percentage Reduction	Effective Factor	Percentage Total Loading	Percentage Reduction	Effective Factor
Ditch Lining & Pipeline	15(4)	90(5)	0.135	0	0		0	100	
Lateral Lining & Pipeline	5(4)	90(5)	0.045	0	0		0	100	
Canal Lining	10(4)	90(5)	0.090	0	0		0	100	
Sprinkler Systems	70(6)	30(7)	0.210	100(8)	30(9)	0.300	90(10)	95(11)	0.855
Sprinklers with Water Mgmt.	70(6)	35(7)	0.245	100(8)	35(9)	0.350	90(10)	95(11)	0.855
Water Mgmt. Imp.	70(6)	30(12)	0.210	100(8)	30(12)	0.300	90(10)	50(13)	0.450
Irrigation Efficiency Imp.	70(6)	10(12)	0.070	100(8)	10(12)	0.100	90(10)	50(13)	0.450
Sediment Ponds	0	0		0	0		90(10)	70(11)	0.630
Tailwater Recycling	0	0		0	0		90(10)	70(11)	0.630
Buffer/Filter Strip	0	0		0	0		90(10)	35(11)	0.315
Grassed Waterways	0	0		0	0		90(10)	30(11)	0.270
Fertilizer Mgmt.	0	0		100(8)	30(9)	0.300	0	0	
Land Leveling	70(6)	10(11)	0.070	100(8)	5(11)	0.050	90(10)	5(11)	0.045
Drainage Systems	70(6)	10(11)	0.070	100(8)	5(11)	0.050	0	0	

TABLE 3-6. (CONT'D.) LOADING-REDUCTION EFFECTIVENESS FACTORS

(1) Percentage of total pollutant loading to groundwater and/or surface water system attributable to an existing practice.

(2) Percentage reduction in pollutant loading for each pollutant as a result of BMP application.

(3) Effectiveness of BMP in reducing total pollutant load ((1) x (2) ÷ 100%)

(4) See Table 2-A, Table 2-B
Assume salinity loading to IRF (groundwater) is directly proportional to seepage volumes within problem areas.

(5) Lining and/or pipelines reduce total conveyance seepage by 90%.

(6) Contribution of field leaching is 70% of total loading. See Table 2-B (leaching requirement + excess leaching).

(7) Without water management reduce excess leaching 80% or 80% of 35% = 30%.
With water management reduce excess leaching 100% or 100% of 35% = 35%.

(8) Assume 100% of nitrate loading to groundwater is from a field leaching of nitrates.

(9) Assume nitrate loading 35% leaching requirement
35% excess leaching
30% nitrogen fertilizer
Without water management 80% of 35% = 30%
With water management 100% of 35% = 35%

(10) Assume 90% of sediment load is from irrigated agriculture field runoff.

(11) From Toups

(12) 80% of excess leaching = 30%.
30% of excess leaching = 10%.

(13) Water management could reduce tailwater by at least 50%.
Cutback systems could reduce tailwater by at least 50%.

In order to compare various BMP's and their pollutant reduction effectiveness in terms of costs, all costs have been reduced to cost per acre.

Some BMP's are capital intensive. Table 3-7 shows costs/acre for these BMP capital investments. Land leveling at $400/A. is highest, sprinkler systems (center pivot) at $300/A second, and sediment ponds $15/A least expensive.

Realizing canal sizes vary and center pivot sprinkler sizes can range from 50 to 500 acres, etc., reasonable average figures were used. Estimates of number of miles of ditches, laterals, and canals were developed.

Equivalent annual costs for capital investments and operation and maintenance (labor included) costs for assumed 20 year life and projected useful life were tabulated. Operation and maintenance costs were based on percentages of total investments or labor costs.

Forty year useful life was used for each capital intensive BMP except sprinklers and tailwater recycle systems for which 20 years was used. Costs per acre are on Table 3-8 and costs per unit are on Table 3-9. Operation and maintenance and useful lives are shown in their respective columns.

Several best management practices have benefits associated with them, such as decreased labor, increased crop yield, and decreased production costs. Estimated benefits are presented in Table 3-10.

Operation and maintenance decreases are in the form of less labor per acre per irrigation or less labor for ditch maintenance. Increased crop yields per acre can be attributed to more uniform application distribution from sprinklers, timeliness of irrigations, elimination of seep areas, more available water, and less nutrient loss from excess leaching.

TABLE 3-7. CAPITAL COSTS OF BMP'S

BEST MANAGEMENT PRACTICES	COST/UNIT	UNITS/ACRE	COST/ACRE
Ditch Lining & Pipeline (0-3 cfs)	20,000/mile	7 miles/640 A.	220
Lateral Lining & Pipeline (3-30cfs)	40,000/mile	1.65 miles/640A. (1)	100
Canal Lining	90,000/mile	1.65 miles/640A. (1)	230
Sprinkler Systems	40,000/sprinkler	1 sprinkler/130A.	300
Sprinklers with water management	40,000/sprinkler	1 sprinkler/130A.	300
Water Mgmt.Imp.			
Irrig. Efficiency Imp.			
Sediment Ponds	1,000/pond	2/160A.	15
Tailwater Recycling	12,000 each	2/160A.	150
Buffer/filter strip			
Grassed waterways			
Fertilizer Management			
Land Leveling	400/A.		400
Drainage Systems	20,000/mile	1 mile/80A.	250

(1) $\frac{\text{1200 miles}}{\text{714 miles}^2}$ = 1.65 miles/640A.

when

$\frac{\text{total length of laterlas or canals}}{\text{irrigated acreage served by surface water}}$

TABLE 3-8. ANNUAL COSTS PER ACRE

BEST MANAGEMENT PRACTICES	Capital Invest.	O & M (Labor)	(DOLLARS/ACRE) EQUIVALENT ANNUAL 20Yr. Life	Useful Life Yrs.	EQUIV. ANNUAL COST - USEFUL LIFE	TOTAL ANNUAL 20Yr. Life	TOTAL ANNUAL Useful Life
Ditch Lining & Pipeline	220	7	22	40	18	29	25
Lateral Lining & Pipeline	100	3	10	40	8	13	11
Canal Lining	230	7	23	40	19	30	26
Sprinkler Systems	300	24	30	20	30	54	54
Sprinkler with Water Mgmt.	300	24 + 12	30	20	30	66	66
Water Mgmt. Imp. (1)		12				12	12
Irrig. Efficiency (2)		165				165	165
Sediment Ponds	15	1	2	40	1	3	2
Tailwater Recycling	150	43	15	20	15	58	58
Buffer/filter strip (3)		1				1	1
Grassed Waterways (3)		1				1	1
Fertilizer Mgmt.							
Land Leveling	400	12	40	40	33	52	45
Drainage Systems	250	8	25	40	20	33	28

i = 7.75%

crf @ i, 20 yr = 0.0999

crf @ i, 40 yr - 0.0816

TABLE 3-8. (CONT'D.) ANNUAL COSTS PER ACRE

(1) $12 annual cost includes purchase of flow measuring devices, Irrigation Scheduling Service, and Education Program.

(2) Double the O & M Cost (labor) of furrow irrigation by cut-back operation on shorten length of run. From Doanes OM = $82/A. for furrow irrigation.

(3) For filter strip 8.25 foot wide strip at bottom of 1/4 mile rows # of miles of strip = # of acres taken out of production.
For each acre of crop 0.00625 acres = 0.001 A. are taken out of production. Therefore, for corn at $300/A. value cost is $.30/A.
Use maximum of $1/A.
Use same for grassed waterways.

TABLE 3-9. ANNUAL COSTS/DOLLARS

BEST MANAGEMENT PRACTICES	Capital Costs	O & M Costs	Annual Costs	Annual Costs		Total Annual Costs	Total Annual Costs
			20 Yr. Life	Useful Life Years	An.Cost for Useful Life	20 Yr. Life	Useful Life
Ditch Lining & Pipeline	20,000/mi.	600	2000	40	1630	2,600	2,230
Lateral Lining & Pipeline	40,000/mi.	1200	4000	40	3260	5,200	4,460
Canal Lining	90,000/mi.	2700	8990	40	7340	11,690	10,040
Sprinkler Systems	40,000/mi.	3200	4000	20	4000	7,200	7,200
Sprinklers without Water Mgmt.							
Water Mgmt. Imp.		12					
Irrig. Efficiency Imp.		165					
Sediment Ponds	1,000/unit	60	100	40	80	160	140
Tailwater Recycling	12,000/unit	720	120	20	120	840	840
Buffer/filter strip							
Grassed waterways							
Fertilizer Management							
Land Leveling	400/A.	12=10	40	40	30	50	40
Drainage Systems	20,000	600	2000	40	1630	2,600	2,230

i = 7.75%
crf @ i, 20 yr. = 0.0999
crf @ i, 40 yr. = 0.0816

TABLE 3-10. BENEFITS PER ACRE

BEST MANAGEMENT PRACTICES	DOLLARS/ACRE/YEAR Decrease O&M (Labor)	Increase Crop Yield	Other Benefit	Total Annual Benefit
Ditch Lining or Pipeline	10(1)		15(2)	25
Lateral Lining or Pipeline	5(3)			5
Canal Lining	5(4)			5
Sprinkler Systems	75(5)	30(6)		105
Sprinkler with water mgmt.	60(7)	30(8)		90
Water mgmt.improvement		30(9)		30
Irrigation efficiency improvement		30(10)		30
Sediment Ponds				
Tailwater Recycling			30(4)	30
Buffer/filter strip				
Grassed waterways				
Fertilizer management			5(12)	5
Land Leveling			15(13)	15
Drainage Systems			15(14)	15

Average crop yield (value)per acre = $\frac{30.6 + 151.9}{500{,}000} - 17.6 = \$325/A.$

TABLE 3-10. (CONT'D.) BENEFITS PER ACRE

---

(1) \$31.50/A/yr. - earth ditch, siphon tubes 1
\$22.50/A/yr. - concrete ditch, siphon tubes 2
\$15.30/A/yr. - gafed pipe

$$\frac{\$11.50 + \$15.30}{2} = \$18.90$$

Convert from 1 to 2 \$31.50 - \$18.90 = \$12.60 = \$12.50

(2) 5% clear up seep spots = \$15 (see 6)

(3) Estimate \$5/acre

(4) Estimate \$5/acre

(5) \$70/A/yr. flood irrigation 150,000A. = 10.5 million
\$150/A/yr. furrow irrigation 300,000A. = 45 million

\$55.5 million for 450,000A. = 123 = \$120/A.

Sprinkler irrigation = 42 = \$45

Difference is \$75/A/yr.

(6) Present average value = \$325/A/yr.
10% increase = 32.5 = \$30/A/yr.

(7) 120 - 45 + 15 - \$60/A/yr.

(8) 10% increase = \$30/A/yr.

(9) 10%

(10) 10%

(11) 10%

(12) Decrease fertilizer use from 200# Ammonia NO_3 to
100# = 100# saved @ 7¢/16 = \$7/A = \$5A/yr.

(13) 5%

(14) 5%

The final step is to find the net cost and divide by the effectiveness factor. In some cases benefits exceeded costs (sprinkler systems) and the final cost minus benefit/effectiveness is a negative number indicating not only can irrigation return flow quality be improved, but also on-farm benefits will be realized.

Benefits of basin-wide improved water quality have not been included, nor has the benefit of water conservation for the area. These are represented in the effectiveness factor.

Tables 3-11, 3-12, and 3-13 illustrate the result of comparison of effectiveness to net cost (cost-benefit). While the analysis is based on potential on-farm costs and benefits, other factors may influence implementation.

3.4.4 Conclusion

Sprinkler systems with or without water management rank 1-2 for each pollutant. Labor savings of sprinklers contributed to a net economic benefit.

Efficiency improvements (high operation and maintenance-labor), drainage systems, and land leveling (high investment) rank towards the bottom.

While conveyance system improvements rank high in controling water loss (water conservation), the cost-effectiveness is not as high as improvements in application systems.

This analysis serves as a comparison tool and not as an absolute water quality model.

Areas that experience all three pollutant problems may combine BMP's for optimum cost-benefit/effectiveness.

TABLE 3-11. COMPARISON OF EFFECTIVENESS TO NET COST - SALINITY

BEST MANAGEMENT PRACTICES FOR SALINITY	REDUCT. EFFECT. FACTOR	ANNUAL COSTS/ ACRE	ANNUAL BENEFITS/ ACRE	COST-BENEFIT / EFFECTIVENESS	RANKING
Conveyance System Improvements					
Ditch Lining or Pipeline	0.135	25	25	0	4
Lateral Lining or Pipeline	0.045	11	5	0.13	5
Canal Lining	0.090	26	5	0.23	7
Sprinkler Systems					
No water mgmt.	0.210	54	105	-0.24	1
With water mgmt.	0.245	66	90	-0.10	2
Water Management Improvements	0.21	12	30	-0.09	3
Efficiency Improvements	0.070	165	30	1.93	9
Land Leveling	0.070	45	15	0.43	8
Drainage Systems	0.070	28	15	0.19	6

TABLE 3-12. COMPARISON OF EFFECTIVENESS TO NET COST - NITRATES

BEST MANAGEMENT PRACTICES FOR NITRATES	REDUCT. EFFECT. FACTOR	ANNUAL COSTS/ ACRE	ANNUAL BENEFITS/ ACRE	COST-BENEFIT / EFFECTIVENESS	RANKING
Sprinkler Systems					
No water mgmt.	0.300	54	105	-0.17	1
With water mgmt.	0.350	66	90	-0.07	2
Water management improvements	0.300	12	30	-0.06	3
Efficiency improvements	0.100	165	30	1.35	7
Fertilizer management	0.300	0	5	-0.02	4
Land Leveling	0.050	45	15	0.60	6
Drainage Systems	0.050	28	15	0.26	5

TABLE 3-13. COMPARISON OF EFFECTIVENESS TO NET COST - SEDIMENT

BEST MANAGEMENT PRACTICES FOR SEDIMENT	REDUCT. EFFECT. FACTOR	ANNUAL COSTS/ ACRE	ANNUAL BENEFITS/ ACRE	COST-BENEFIT / EFFECTIVENESS	RANKING
Sprinkler Systems					
No water mgmt.	0.855	54	105	-0.06	1
With water mgmt.	0.855	66	90	-0.03	3
Water management improvements	0.450	12	30	-0.04	2
Efficiency improvements	0.450	165	30	0.30	6
Tailwater Control					
Sediment ponds	0.630	2	0	0.01	4
T.W.Recycling	0.630	58	30	0.04	5
Buffer/filter strip	0.315	1	0	0.01	4
Grassed waterways	0.270	1	0	0.01	4
Land Leveling	0.045	45	15	0.67	7

4.0 POLLUTANTS ASSOCIATED WITH IRRIGATION RETURN FLOW AND THEIR EFFECTS UPON BENEFICIAL USE

The term "pollution" means the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water (P.L. 92-500, Sec. 502-19). When substances are present in suffucient concentrations (whether through man-induced or natural causes), they may adversely affect the suitability of the water for one or more beneficial uses.

Beneficial uses of water include the many purposes that water serves in promoting the economic good and general well-being of mankind. The following is a list of common uses:

- Domestic Water Supply
- Industrial Water Supply
- Agriculture Irrigation Water Supply
- Stock and Wildlife Watering
- Propagation of Fish and Water-Contact Sprots
- Boating and Aesthetic Enjoyment
- Water Power and Navigation

States have established Water Quality Standards as maximum allowable pollutant concentrations for various water bodies. These standards are generally based on beneficial uses for the various water bodies.

The relationship of irrigated agriculture to water pollution is complicated. Some of the major polluting substances involved, such as sediments, salts, and nutrients, are natural components of the countryside. Others are added to the systems as a result of attempts to increase agricultural production. These include pesticides and fertilizers.

This chapter briefly describes the major pollutants associated with irrigated agriculture:

- Salinity - including sodium, chlorides, and other potentially harmful ions
- Sediment
- Nitrates
- Phosphorus
- Pesticides
- Organics

Each pollutant is defined, and effects upon beneficial uses are listed. The pollutant's relationship to irrigated agriculture is described in terms of sources and return flow mechanisms.

4.1 SOURCES AND LOADING MECHANISMS FOR POLLUTANTS EMANATING FROM IRRIGATED AGRICULTURE

4.1.1 Salinity

Dissolved solids, consisting of carbonates, bicarbonates, chlorides, sulfates, phosphates, and possibly nitrates combined with calcium, magnesium, sodium, and potassium, are commonly referred to as salts or salinity. Salinity levels are usually measured as Total Dissolved Solids (TDS) or are measured indirectly as electrical conductivity. Concentrations of the various ions involved are also significant.

At certain concentrations, salts in the soil solution may impair the osmotic process of water uptake by plant roots. The degree to which plant growth is inhibited is generally expressed in terms of the total salt concentration of the soil solution. While the various ions involved play a significant role, most data developed to date deals with plant tolerance in terms of total dissolved solids or electrical conductivity.

Two specific ions, sodium and chloride, are of special significance. Water with a high sodium percentage is detrimental to soil structure. Water which is high in chlorides may be toxic to plants. Other constituents may also be of concern. Section 4.3.1 of this report deals with salinity and specific ion concentrations in terms of effect upon beneficial uses, including irrigation.

Salinity Loading Mechanisms

Salt levels in the waters of irrigated regions are primarily the result of concentration resulting from consumptive use. All waters used for irrigation contain some salts. As this water is used by plants (transpiration) and evaporated from the soil, salts remain behind in the soil water. As the salts become more concentrated, some of the less soluble salts may precipitate. Subsequent irrigation results in the downward movement of the soluble salts. This leaching of salts from the root zone is essential in terms of maintaining a favorable soil salinity. This leaching of salts is also the primary loading mechanism for saline return flows. Reuse of this water results in further concentration.

Natural Salt Load

Salts originally enter the system through three loading mechanisms:

- Atmospheric contact;
- Weathering of rocks and soils as rainfall and snowmelt infiltrate into the ground, percolate through the ground, and enter the ground water. This ground water may or may not enter a stream;
- Weathering of rocks and soils as rainfall and snowmelt runoff proceeds to a stream via overland flow.

The initial salt load resulting from atmospheric contact is negligible and unavoidable. The initial salt load resulting from natural percolation and runoff is highly variable depending upon local conditions. While some streams contain high quality natural waters, other streams are naturally high in salts.

The Effects of Irrigated Agriculture Upon Salt Load

Irrigated agriculture - the use of water for crop production - results in increased salt concentrations in subsurface returns. Irrigated agriculture may or may not result in increased salt loads. That is, the total tonnage of salt leaving an irrigated area may be less than the tonnage of salt entering that area.

Increased salt concentrations associated with irrigated agriculture are the results of several factors:

- Evapo-transpiration from croplands;
- Evaporation from water bodies
- Evapo-transpiration by water loving plants (phreatophytes) and from wet lands;
- Salt pickup from irrigation of soils which are ither themselves saline or which overlie saline rock or soils.

Of these factors, only salt pickup results in an increased total salt load. All of the factors listed result in increased salt concentrations, however. Evapo-transpiration from croplands is the only factor which is significant in all irrigated areas.

The fact that the overwhelming burden of salt concentration is the result of cropland evapo-transpiration poses a distinct limitation on our ability to decrease salinity in Western waters. Methods aimed at salinity control must either decrease non-beneficial consumptive use, decrease salt pickup where it occurs, or segregate very highly-saline return flows from returning to the system.

Evapo-transpiration from croplands is the major salt concentration mechanism. While the majority of this evapo-transpiration is necessary, it is possible to reduce some of this evapo-transpiration without reducing yield. Reducing weed growth, changing to trickle irrigation, reduction of urban lawn watering, reduction or elimination or irrigation of marginal lands, operation of sprinklers only at minimal evaporation times of the day, and minimization of the number of irrigations are examples of how evapo-transpiration from irrigated lands can be reduced without significantly reducing yield. None of these examples can be considered to be outstandingly effective, however; and many are unacceptalbe within the context of current economics, social constraints, and water availability.

Reduction of evaporation from water bodies offers marginal possibilities at best. Evaporation losses are estimated to be 2.8 x 10^{10} m^3 (2.3 x 10^7 acre feet) annually (Lauritzen, et.al., 1967). In some cases, canal consolidation may be possible.

Reduction of phreatophyte use offers some possibilities for reducing non-beneficial consumption use. In many surface irrigated areas, canals, ditches, and lakes are run down and lined with willows, cottonwood, and other water-loving plants. It has been estimated that in the Western United States, phreatophyte use is around 3.1 x 10^{10} m^3 (2.5 x 10^7 acre feet) (Jensen, et.al, 1967). Much, if not most, of this phreatophyte use occurs along natural streams and areas of high ground water, however.

Salt pickup from irrigation of saline soils or soils over saline rock formations occurs in only a few areas of the West. In these areas, control measures aimed at reducing contact may be able to show some results.

Leaching of Agricultural Soils

Continued irrigated agriculture requires maintenance of a favorable soil salinity. This favorable soil salinity is maintained by the application of more water than is required to fill the root zone. This is generally not a calculated practice. That portion of water which moves below the bottom of the root zone is called the leaching fraction.

$$LF = \frac{\text{depth of water moving below root zone}}{\text{depth of water applied plus effective rainfall}}$$

LF = Leaching Fraction

When the total amount of salts removed by the leaching fraction equals the amount of salt applied with the irrigation water, the field is said to have a salt balance. In practice, a salt balance is often not met due to precipitation of salts within the root zone. Less soluble salts may precipitate in and below the root zone. The most soluble salts are readily leached, however. The concept of salt balance may be applied to a field or an irrigation district. The salt balance is determined by an accounting procedure.

Figure 4-1 shows a soil profile with the various inputs and outputs of salt and water. Several computer programs are available for modeling soil salinity and stream loading (Hornsby 1973 and King, et.al. 1973). Hornsby has reviewed the models and suggests that they have reached the level of accuracy where they can be used to evaluate changes resulting from various management practices.

The salt balance is complicated by the water and salt storage capacity of the soil. Concentrations of salts in the soil solution are a function of water present. As water is removed by evapo-transpiration, stored salts become more critical. Salinity sensors are available to monitor soil salinity (Wesseling and Oster 1973).

Irrigation water provides the major input of salts to the soil profile of irrigated land. The amount of salts added is equal to the volume of water which infiltrates into the soil multiplied by the concentration of salts in the water. Waters with high concentrations of dissolved solids add a great deal of salts to the soil.

The leaching requirement (LR) is the percentage of applied water that must be leached beyond the root zone necessary to maintain a favorable soil solution salinity. It will vary depending on the concentration of salts in the applied water and the maximum allowable salinity tolerance levels for specific crops.

Total salinity is comprised most imporantly by calcium, magnesium, and sodium salts. Calcium and magnesium in the proper proportions maintain soil in good condition of tilth and structure, while the opposite is true when sodium

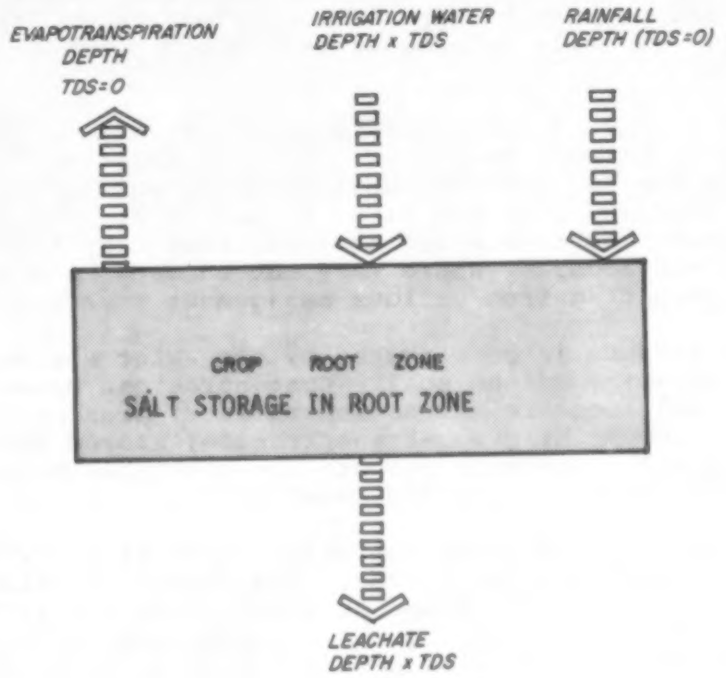

EVAPOTRANSPIRATION
DEPTH
TDS=O
IRRIGATION WATER
DEPTH x TDS
RAINFALL
DEPTH (TDS=O)
CROP ROOT ZONE
SALT STORAGE IN ROOT ZONE
LEACHATE
DEPTH x TDS

FIG. 4-1. WATER AND SALT BALANCE

toups corporation
loveland, co.

predominates. Too much sodium causes the granular soil structure to begin to breakdown when the soil is moistened resulting in sealing of soil pores and a decrease in permeability. Ultimately, the soil pH increases to the level of alkali soils. Special leaching practices may be required when sodium problems exist. The sodium problem is further discussed in the beneficial use section.

In order to keep salt buildup to a minimum and since most irrigators do not have the tools to calculate the LR nor flow measuring devices, excessive amounts of water are often applied. In addition, the LR may vary throughout a field, and water in some irrigation systems is not applied evenly across the field. Since water is relatively inexpensive and nonuse may threaten the water right, the irrigator is motivated to use more water than may be required by the crop.

These factors result in inefficient leaching practices. Recent research has shown some ways to make leaching more efficient. It has been found that the total seasonal salt discharge from a tile drainage system was directly related to the quantity of water discharged (King and Hanks 1975). With small leaching fractions, the salt would be more concentrated, but the discharge would carry less total amounts of salt.

Frequent leaching under unsaturated soil conditions has been shown to be more effective than under saturated conditions (Lathin, et.al., 1969).

While the alteration of leaching practices may reduce total salt loading, such practices can result in other problems. Potential problems include increased salt concentrations for users directly dependent upon drainage water as a water supply. In addition, alteration of leaching practices can potentially increase the proportion of hazardous ions.

4.1.2 Sediment

Surface irrigation,particularly furrow irrigation, is significant in producing erosion; however, the problem is site specific. The National Engineering Handbook on Sedimentation comments that "...no method exists to preduct rates of waste load transport without a substantial amount of data on suspended concentrations during measured discharges (USDA 1968).

The Universal Soil Loss Equation has been used extensively to predict soil loss from agricultural lands under rainfall conditions. However, it is not applicable to the conditions encountered during irrigation. Rainfall conditions sufficient to produce runoff result in an increase in flow with distance traversed. Conversely, during the process of surface irrigation, the flow decreases with distance.

Tests conducted in Idaho on four small fields ranging from three to nine acres have indicated a wide range of sediment loadings (University of Idaho 1974).

4.1.3 Nitrogen

Nitrate (NO_3), nitrogen, is a pollutant which is associated with leaching returns from agricultural soils. The potential for nitrate leaching is greater in sandy soils. While nitrogen may be added to the soil in many forms, soil bacteria oxidizes these forms to the soluble nitrate form (Figure 4-2).

Relationship to Irrigated Agriculture

There are several sources of nitrogen for the soil-plant environment. Fertilizers are well known as sources, but fertile soil itself is a pool of nutrients. Nitrogen fixation, a process in which legume crops and microorganisms biologically convert atmospheric nitrogen into usable organic nitrogen, is another common source. Precipitation picks up nitrogen. Animal wastes and plant residues also provide inexpensive nitrogen to the soil. Relative contributions vary considerably.

Fertilizers add nitrogen to the soil. Examples of chemical fertilizers are Ammonium Sulfate $(NH_4)_2 SO_4$, Ammonium Nitrate NH_4NO_3, Urea $CO(NH_2)_2$, and Anhydrous Ammonia liquid NH_3.

The ammonium fertilizer divides into four pathways. Soil organisms absorb a considerable portion of the ammonium. Second, higher plants are capable of using this form of nitrogen, especially young plants. Third, NH_4 may be fixed by clay, minerals, and organic matter. In this form, it is not readily available, but is subject to slow release. Finally, the remaining NH_4 is subject to nitrification, resulitng in Nitrate (NO_3).

The nitrogen contained in soil organisms is not considered to be readily available to the plant, nor is it mobile within the soil. This nitrogen is not lost, however, as it is subject to slow release as organisms decay. Ammonium adsorbed on soil particles is not particularly mobile within the soil. Ammonium is also unstable in the soil system.

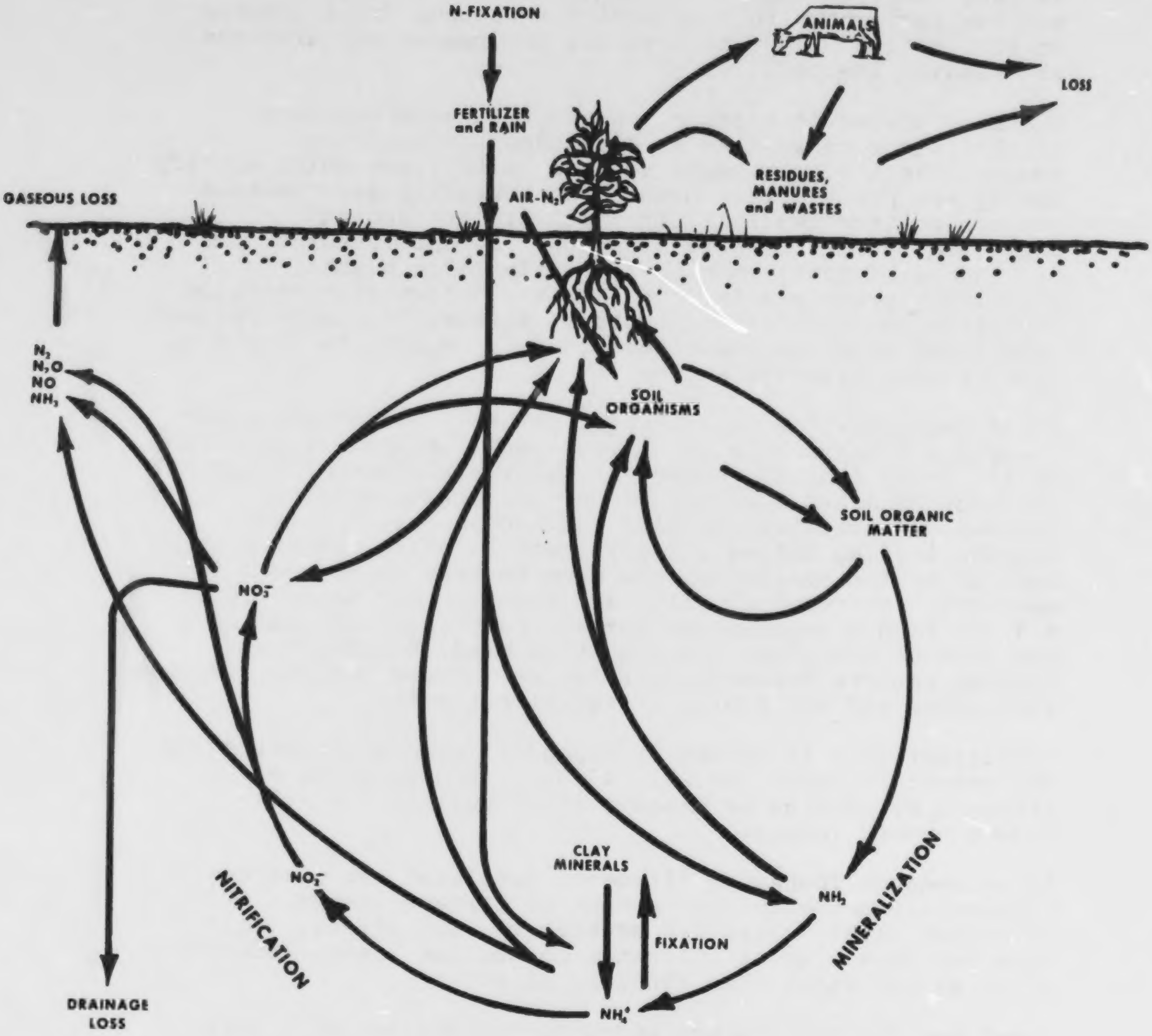

N-FIXATION
ANIMALS
LOSS
FERTILIZER and RAIN
RESIDUES, MANURES and WASTES
GASEOUS LOSS
AIR-N_2
N_2
N_2O
NO
NH_3
SOIL ORGANISMS
SOIL ORGANIC MATTER
NO_3^-
NO_2^-
CLAY MINERALS
FIXATION
NH_3
NH_4^+
NITRIFICATION
MINERALIZATION
DRAINAGE LOSS

FIGURE 4-2 THE NITROGEN CYCLE

Under well-aerated conditions, nitrification is complete within a few feet of the soil surface (Pruvel 1968). Nitrate (NO_3) is highly soluble in water and highly mobile and has been shown to move with the wetting front (Edward, et.al., 1972). These factors are the reason why nitrates are readily leached.

Leaching losses of nitrate represent an economic loss to the farmer as well as an environmentel pollutant source. As a result, slow release fertilizers which nitrify slowly are preferable. Methods of achieving slow release include coating the fertilizer pellets and adding chemicals to inhibit nitrification. Recent research has indicated that ammonium is available to plants, especially young plants. This provides further motivation inhibiting nitrification. Urea is a relatively slow release fertilizer which is now in common use. Manure is also a slow release nitrogen source.

Since seepage is the major export pathway, irrigation water use plays a major role in nitrate loss. Balton, Aylesworth, et.al, found that the amount of water percolated through the root zone had a direct effect on nitrate loading. Increased fertilizer use will not necessarily increase nitrate loading unless a significant leaching fraction is applied or the ability of the crop to take up nitrogen is exceeded. Erickson and Ellis and Hendrick and Letey (1975) did not find a correlation between fertilizer use and seepage loss of nitrates. On the other hand, Broadbent and Chapman found a definite correlation. These results indicate that crops and soils play a significant role.

Fertliizer loss in runoff is dependent upon application and management (Timmons, et.al., 1973). Incorporation of nitrogen by plowing or discing after application will reduce runoff losses.

As in seepage losses of nitrogen, fertlizer use does not necessarily determine the amount of surface losses. Uttormark (1974) cites two studies to this effect. Soil type can have a great influence on surface losses (Sievens 1970) as can water flow (Taylor, et.al.).

Sometimes fertilizers are added to and applied with irrigation water. Since nitrates are highly soluble in water, bypass water and tailwater can transport to receiving streams, if not managed properly.

4.1.4 Phosphorus

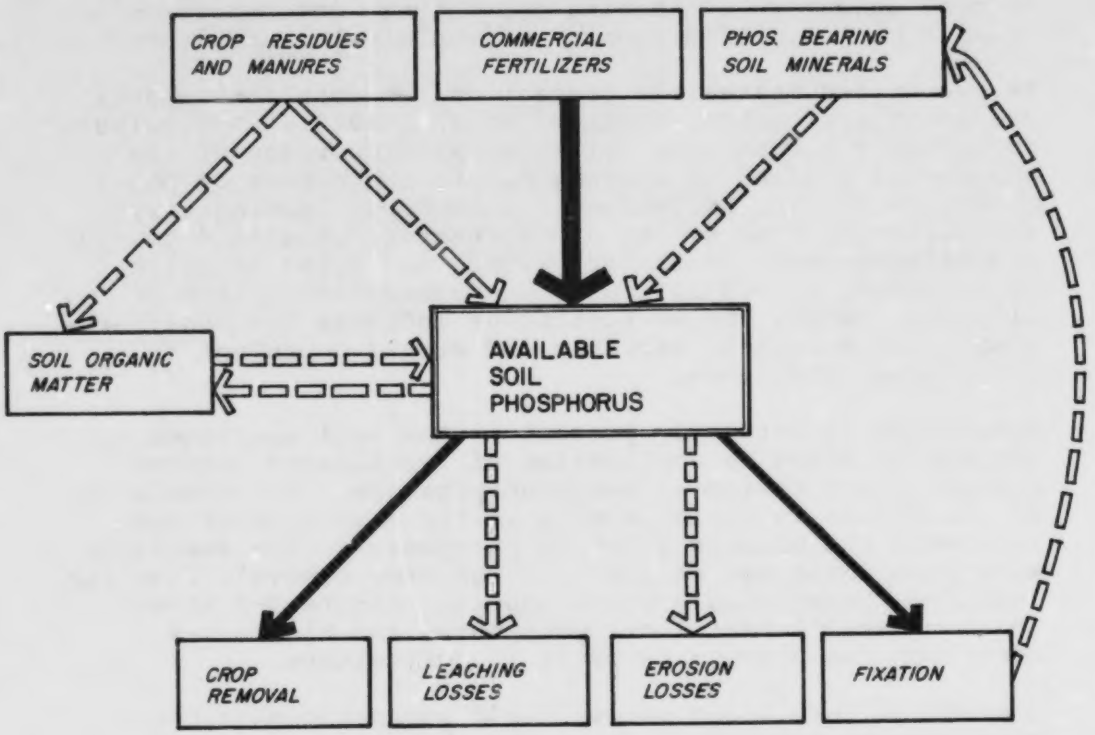
Phosphorus does not occur free in nature but is found in the form of phosphates. Phosphates contained in surface waters or groundwaters are sometimes the result of leaching of minerals or ores, natural processes of degradation, agricultural returns, industrial wastes, discharge of cooling waters containing phosphates, decomposition or organic matter, and discharge of municipal wastewaters.

In the United States, 76 percent of the total phosphorus use is by agriculture (Kramer, et.al., 1972). Agriculture is probably responsible for a lesser proportion of the phosphorus loading to streams due to the nature of phosphorus in soils. Estimates of phosphorus loading vary significantly from 0.5 to 4.5 kg/hectare/year (0.4 to 4.0 pounds/acre/year) (Task Group 1967) and 0.003 to 1.1 kg/hectare/year (0.003 to 1.0 pounds/acre/year) (State of Illinois, 1972). These statistics indicate the phosphorus loading is extremely variable and highly dependent on locatlized conditions.

Phosphorus is naturally present in the soil environment and can be added by application of fertilizers, animal wastes, plant residues, and precipitation. The chemistry of phosphorus in soils results in the existence of both inorganic and organic forms of phosphorus. The available soil phosphorus can be lost through crop removal, fixation, leaching losses, and erosion losses. Figure 4-3 shows the pathways of fertilizer phosphorus and Figure 4-4 describes the phosphorus cycle in agriculture.

Commercial fertlizers commonly add inorganic phosphorus compounds to the soil. Ortho-phosphate ions have a great affinity for various cations inthe soil: $CA+^{2}$, $Fe+^{3}$, $Zn+^{2}$, $A+^{3}$. In alkaline soils, compounds of calcium predominate. Of the phosphorus added as fertilizer, most is fixed to the soil in this manner. These inorganic phosphorus compounds are slightly soluble although a small portion of the fixed phosphorus may become available with time. The availability of this inorganic phosphorus is a function of pH, with maximum availabilitiy between pH 5.5 and 7.0 (Buckman and Brady, 1969). In the alkaline soils of the West, availability is quite low since the calcium-phosphates are not very soluble.

The ability of soils to fix phosphorus in inroganic compounds is enormous. A study of Mexico silt load indicated that two plots had similar ability to absorb phosphates


CROP RESIDUES AND MANURES
COMMERCIAL FERTILIZERS
PHOS. BEARING SOIL MINERALS
SOIL ORGANIC MATTER
AVAILABLE SOIL PHOSPHORUS
CROP REMOVAL
LEACHING LOSSES
EROSION LOSSES
FIXATION

[Major pathways (heavy lines) are fixation and crop removal.]

FIG. 4-3. PATHWAYS OF FERTILIZER PHOSPHORUS

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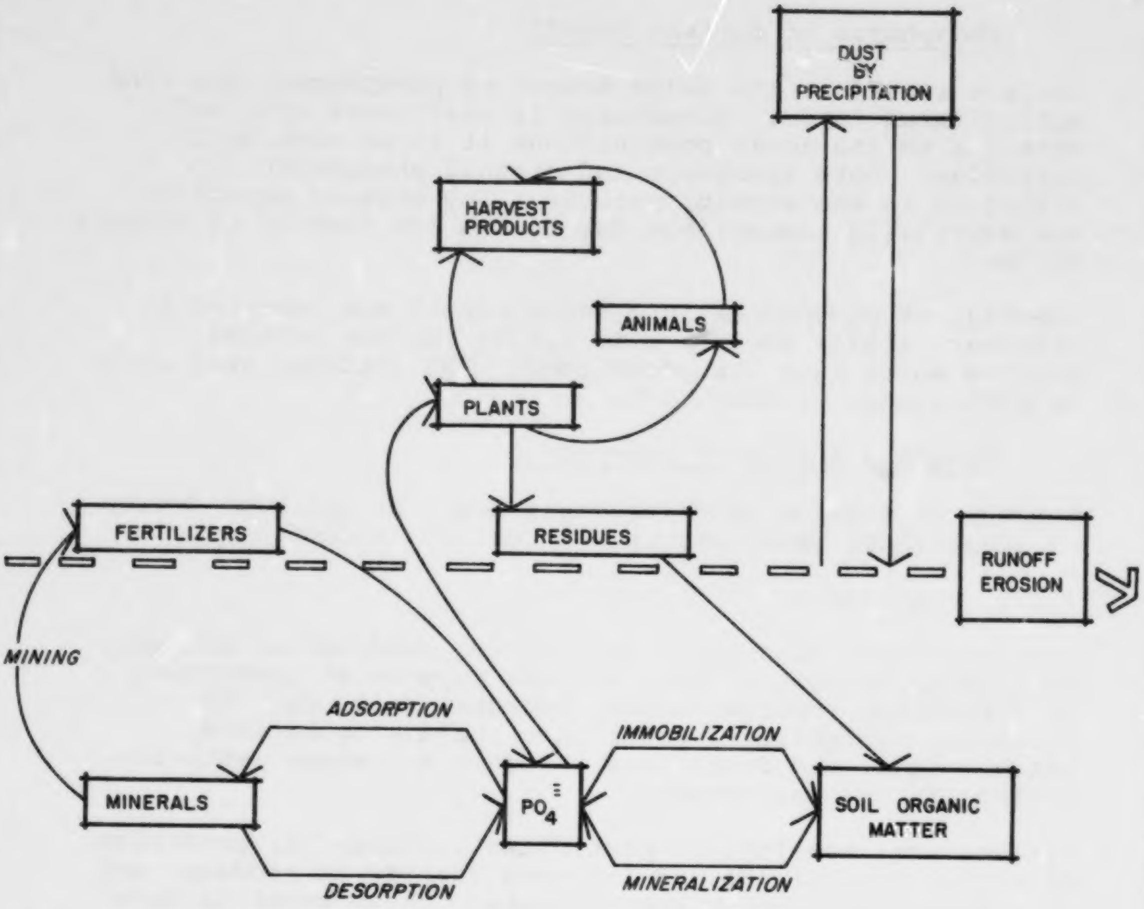
DUST BY PRECIPITATION
HARVEST PRODUCTS
ANIMALS
PLANTS
FERTILIZERS
RESIDUES
RUNOFF EROSION
MINING
ADSORPTION
IMMOBILIZATION
MINERALS
$PO_4^{\equiv}$
SOIL ORGANIC MATTER
DESORPTION
MINERALIZATION

FIG. 4-4. THE PHOSPHORUS CYCLE IN AGRICULTURE

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where one of the plots had received phosphate fertilization for 82 years and the other was fertilized for the first time (Kao and Blancher, 1973).

Phosphorus in Surface Runoff

Surface runoff is the major source of phosphorus loss from agricultural lands. Phosphorus is associated with sediment due to the ionic combinations it forms with soil particles. Both inorganic and organic phosphorus are picked up in the erosion process. The organic materials are especially susceptible due to the low density of organic matter.

Loadings of phosphates in surface runoff are reported by Uttormark (1974) and Porcella (1974) for the several studies which have been conducted. The loadings vary over several orders of magnitude.

Drainage Losses of Phosphorus

Because of the low solution concentrations and high degree of adsorption, phosphate is not readily leached.

4.1.5 Pesticides

Pesticides are substances used during production, storage, and transportation of food for the purpose of preventing or destroying insects, weeds, rodents, or fungi. In irrigated agriculture, pesticides include herbicides, insecticides, and fungicides. Figure 4-5 shows pesticide cycling in the environment.

Agricultural benefits of pesticides include: 1) promotion of higher crop yields; 2) improved quality of produce; and 3) reduced cultivation requirements. These benefits have resulted in economic benefits to the farmer and the consumer. Insecticides, herbicides, and fungicides will continue to be used if our level of agricultural production is to be maintained or increased.

Some pesticides have a great affinity for soil particles and organic material and as a result are transported with sediment. Others are highly soluble and subject to transport to leachate and as the soluble portion of runoff. The Soil Conservation Service (SCS) has categorized 171 agricultural pesticides according to the mode of transport. The results are summarized below:

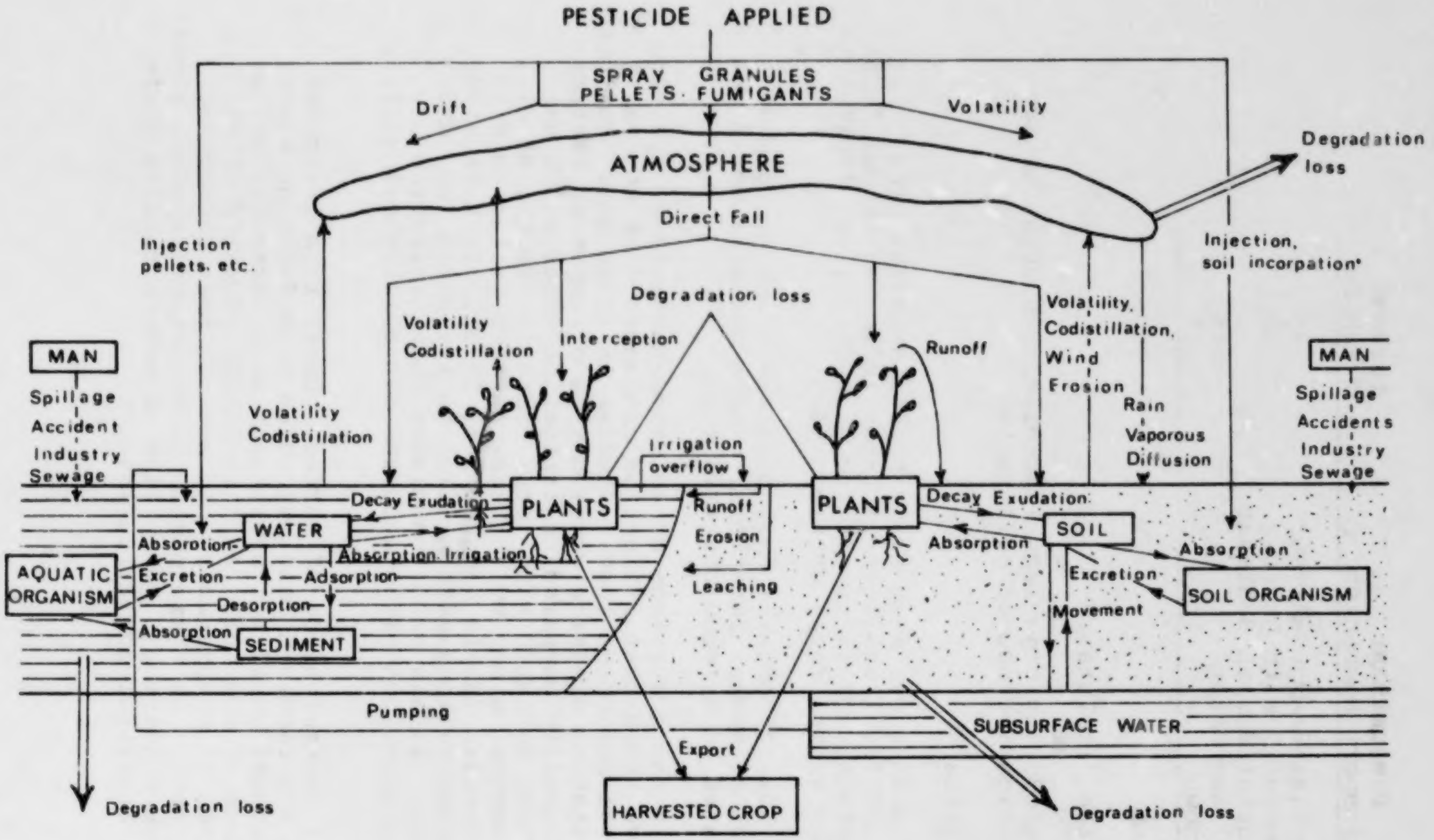
PESTICIDE APPLIED
SPRAY GRANULES
PELLETS FUMIGANTS
Drift
Volatility
ATMOSPHERE
Degradation loss
Direct Fall
Injection pellets. etc.
Injection, soil incorporation
Degradation loss
Volatility Codistillation
Interception
Volatility Codistillation
Runoff
Volatility, Codistillation, Wind Erosion
Rain Vaporous Diffusion
MAN
Spillage
Accident
Industry
Sewage
MAN
Spillage
Accidents
Industry
Sewage
Irrigation overflow
PLANTS
PLANTS
Decay Exudation
Decay Exudation
WATER
SOIL
Absorption
Absorption Irrigation
Absorption
Absorption
AQUATIC ORGANISM
Excretion
Adsorption
Runoff
Erosion
Leaching
Excretion
SOIL ORGANISM
Desorption
Movement
Absorption
SEDIMENT
Pumping
SUBSURFACE WATER
Export
HARVESTED CROP
Degradation loss
Degradation loss

FIG. 4-5. PESTICIDE CYCLING IN THE ENVIRONMENT [A]

[A] HYDROCOMP

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Predominant Transport Mechanism	Percent of Sample
Associated with Sediment	46
Associated with Water	30
Associated with Sediment and Water	16
Unknown	8
TOTAL	100

4.1.6 Other Pollutants

Disease-producing organisms (bacteria) and organics are rarely irrigation-caused pollutants.

Bacteria

Some bacteria cause disease in higher animals. The presence of fecal coliform bacteria indicates mammal fecal contamination. Fecal streptococcus bacteria are indicators of grazing animal fecal contamination.

The soil itself contains many bacteria which perform a variety of necessary functions. These bacteria would not be indicated in a fecal bacteria test.

Studies of the occurrence of coliform bacteria in drainage water have shown that irrigation drainages does not exert a bacterial pollution load. Studies in Idaho have indicated that irrigation drainage water may be of improved bacteriological quality compared to irrigation water which was consistently polluted with fecal bacteria (Smith, et.al., 1972). Another study by the same authors failed to find similar results (Smith and Douglas, 1973). In this study, fecal concentrations were similar in irrigation and drainage waters. It was still concluded that irrigation has minimum deleterious effects on the microbiological quality of water.

Bacterial contamination of surface runoff from irrigated cropland has received less attention than drainage water. Surface runoff would not be suspect as a bacterial pollution source except where surface runoff occurred after application of manure which had not yet been incorporated into the soil. In these cases, tailwater or rainfall runoff could erode significant quantities of manure causing a significant bacterial pollution load.

Organics

Organic pollution is associated with crop residue, manure, or humus being lost from the cropland. The subsequent biological oxidation of this organic matter could place an oxygen demand upon the stream. Studies of runoff exerting a biochemical oxygen demand (BOD) have been conducted in the dairy states where manure is applied to frozen ground over the winter in areas with a large spring runoff. These conditions would not be expected to exist in most irrigated regions.

The soil has the capacity to act similar to the trickling filter used in sewage treatement. Bacteria attached to the soil would oxidize most organic matter to CO_2 during its flow through the soil.

Surface runoff or tailwater would be expected to exert a large BOD where runoff occurred from land having manure applied, but not incorporated into the soil. This would be considered to be a rare case, however, as manure is usually plowed in before such events occur.

Temperature

Surface returns from irrigated agriculture may be of increased temperature. Drainage returns would be expected to arrive at soil temperature. Very little work has been done on the increased temperature resulting from irrigation.

4.2 IDENTIFICATION OF WATER QUALITY PROBLEMS ASSOCIATED WITH IRRIGATED AGRICULTURE

Best management practices for irrigated agriculture must be considered in terms of both agricultural practices and local and regional water quality problems. This section presents some information on the relationship between irrigation return flows and water quality problems.

4.2.1 Locating Return Flows

Return flows must be defined in terms of location and quantity. The quality of return flows is equally important and discussed in the next section.

Each irrigated area has its own relationship between water supply, water application method, return flow, and receiving water. Water supply may be either:

- o Surface water;
- o Well water.

Water application methods may be:

- Furrow
- Border
- Dead level
- Wild flooding
- Sprinkler
- Trickle.

There are five basic irrigation return flows in irrigated agriculture:

- Canal seepage
- Bypass water
- Sursurface articifical drainage
- Deep percolation
- Tailwater.

These return flows may impact either:

- Surface water
- Ground water.

Returns which initially impact ground water may end up in surface waters.

Surface return flows can be located and quantified more easily than subsurface flows. Canal seepage and deep percolation return flows can be most readily located by quantifying inflows and outflows which can be located. There are three basic methods for determining the quantity of return flows to a river.

The first method is by consultation with the River Commissioner. As part of the day-to-day job of scheduling diversions, the River Commissioner usually knows where return flows are occurring, and the amounts of seepage and tributary inflows.

A second way is by an inflow-outflow analysis conducted between two points of known flow on the river. By adding tributary inflows and discharges to the river to the upstream known flow, subtracting outflows and diversions from the upstream known flow, and comparing the result with the downstream known flow, the amount gained or lost through seepage can be estimated. If the resultant flow and known flow are equal, a water quality analysis must be performed to determine whether there is an unaccounted pollutant load on the river. If there is, some nonpoint return flow may be reaching the river, while an equivalent amount of river water is lost through seepage or phreatophyte usage.

The third method is by on-site investigations and measurements. Actual measurement of return flow quantities can be taken by flow measurement devices. Seepage inflows may be estimated by taking flow measurements at two points on the river where there are no other outflows or inflows between the points.

Figure 4-6 diagrams a return flow system. While this is a common system, it does not represent all systems. Analysis of each system will require determination of inflows, outflows, and pathways. Determination of these pathways combined with quality analysis of returns and receiving waters is central to understanding and dealing with water quality problems in irrigated areas.

4.2.2 Determination of Return Flow Quality and Quantity

The existence of practices and conditions which result in irrigation return flow does not mean that there are definite water quality problems. The existence of water quality problems may be proven by water quality data already collected. In many cases, however, much more detailed data is necessary. In addition, the water quality data must be correlated to irrigated agriculture return flows.

Monitoring Program

A monitoring program to identify water quality problems should be undertaken at both the on-farm and subregional levels. An on-farm program will involve:

- o Flow measurements of irrigation water;
- o Flow measurements of return flows;
- o Sampling for irrigation water quality;
- o Sampling for return flow quality.

Flow measurements and sampling should take place at the same sites in order to calculate both the quantity of pollutant and the concentration. Concentrations have weight per volume units and can be multiplied by the volume of water to obtain a total pollutant load. Total weight can be more meaningful to a program than concentrations.

A monitoring program at a subregional level would identify water quality problems in the river, or ground water aquifer, and ultimately relate those problems to irrigation return flows. This program will entail:

- o Flow measurements of the river;
- o Sampling for river water quality;
- o Sampling for ground water quality;
- o Diversion records;
- o Tributary inflow.

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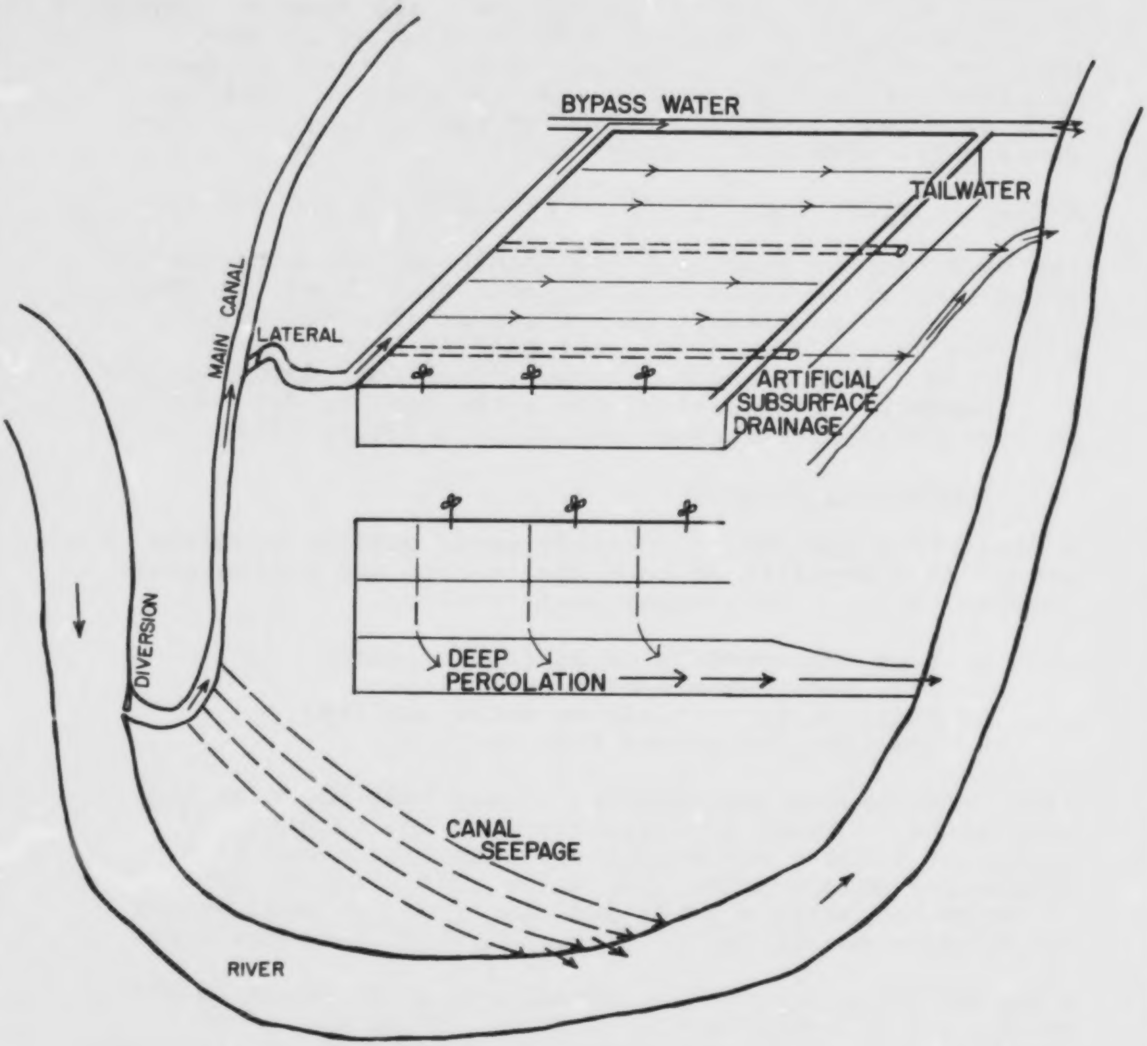
BYPASS WATER
TAILWATER
MAIN CANAL
LATERAL
ARTIFICIAL SUBSURFACE DRAINAGE
DIVERSION
DEEP PERCOLATION
CANAL SEEPAGE
RIVER

FIG. 4-6. IRRIGATED AGRICULTURE RETURN FLOWS
(SURFACE SUPPLY AND RETURN SYSTEM)

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Here again, sampling locations and flow measurement go hand in hand.

An irrigation return flow monitoring program requires selection of sampling and measurement sites, sampling procedures, selection of pollutant parameters, and flow measurement techniques.

Sampling and Measurement Site Selection. Site selection should be based on frequency of data collection, accessibility, good representative samples and measurements, and adequate study area coverage. Samples and measurements will be collected on a regular schedule for some sites and not others. Schedules are dependent on irrigation scheduling and river diversion schedules. Irrigation wells, points of diversion, reservoir outlets, head ditches, drainage outfalls, and return flow ditches are examples of monitoring locations. Ground water samples may require boring and casing of a sampling well at selected locations in the irrigation area.

Sampling Procedures. The following items are essential for good results in a sampling program:

- Samples should be taken at locations where the water is well mixed;
- Large-mouth glass or plastic jars should be used;
- Sufficient volume should be collected to allow re-run of some analyses, if necessary.

Important Pollutant Parameters

In order to carry out a monitoring program it is important to have a general understanding of parameter analyses. The major parameters of concern in an irrigation return flow study are salinity, sediment, nitrogen, phosphorus, and pesticides. Major pollutant pathways (Figure 4-2) will dictate locations of monitoring stations. Other water quality parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), and pH are good indicators of pollution problems in general. For more detailed discussions of parameter analyses, refer to Standard Methods for the Examination of Water and Wastewater (most current edition) and/or Manual of Methods for Chemical Analysis of Water and Wastes (U.S. Environmental Protection Agency, current edition).

Salinity. Salinity may be measured as total dissolved solids or electrical conductivity. Both measurements are acceptable, and it is desirable to measure both in at least the initial stages of a program. Measurement of salinity by both methods allows a check, and may often be used to develop a correlation between the two measurements. More intense study of salinity may focus on specific caitons and anions.

The cations are calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). The relative concentrations of these ions is indicative of possible sodium hazards.

Total dissolved solids is the weight of the residue from a filtered sample after evaporation. Filtration removes suspended matter, and a 40-micron membrane filter is often used; although other sizes may also be used where they fit the circumstances. Drying temperatures of 103°C, or 179-181°C, are used depending upon what is to be measured. Residues dried at 179-181°C generally yield values of dissolved solids most close to that obtained by summation of the various constituents (weight of cations plus weight of anions, Standard Methods). This temperature is recommended for analysis of irrigation return flow.

Total dissolved solids may also be determined by summation of cations and anions. This is an excellent method when full analysis is called for.

Specific conductance yields a measure of a water's capacity to convey an electric current. The conductance of a water is related to the total concentration of ionized substances. The relationship between specific conductance and total dissolved solids is dependent upon the cations and anions involved. The conductance is also dependent upon temperature.

Sediment. Since sediment is due to erosion processes during irrigation and is highly variable in the context of flowing streams, it is hard to quantify. Sediment concentrations can be measured in tailwater flows by analyzing the sample for suspended solids. Tailwater detention ponds can be measured for sediment prior to and after irrigation season to get an estimate of sediment yield.

Suspended solids in a measured volume of sample are collected on a weighed glass fiber pad, dried at 103-105°C, and reweighed. The amount required for analysis is 100 ml.

Nitrogen. Nitrates are the primary form of nitrogen occurring in return flows and in ground waters. Ground water concentrations of nitrates will usually be much higher than surface waters, because of the absence of plants and photosynthesis. As the decomposition process progresses, organic nitrogen is converted to ammonia, and further to nitrite and nitrate. Also, ammonia nitrogen is often added as fertilizer. Therefore, in some cases, other forms of nitrogen should be examined.

Samples for nitrogen forms should be analyzed as soon as possible after collection to avoid loss due to biological activity. These samples should be cooled to 4°C and analyzed within 24 hours. If this is not possible, preservative measures can be taken. At least 25 ml of sample is required to test for nitrate as N.

Phosphorus. The level of effort directed to phosphorus study will be determined by the extent of existing or anticipated algae problems in downstream rivers and lakes. Phosphorus has an affinity for soil particles and is associated more with tailwater than drainage water. The attached phosphorus is not readily available to algae and yet it may become available if other forms of phosphorus are not available. This would be the situation only in the most pure waters. Generally, the orthophosphate group is the only form available. As a result, it is recommended that ortho-phosphates be tested for in irrigation return flow studies. In addition, total phosphorus should be tested for where it may become necessary to have this data in later eutrophication studies. Fifty milliliters is the amount required for analysis.

Pesticides. Due to the very low levels usually present in stream samples and uncertainty as to what levels are significant, a relatively large sample is required for analysis in most surface water. If necessary, any clean glass or metal (avoid plastic) container or combination of containers totalling one-half gallon capacity or more may be used. At least 1,000 ml are required for analysis.

In order to test for particular pesticides, it is beneficial to find out which pesticides are predominantly used in an area. Pesticide analyses are expensive and should not be wasted.

Laboratory Analysis. Laboratory equipment is expensive; thus, it is advantageous to have samples analyzed by existing laboratories.

- Consulting engineering firms, environmental testing labs, and other testing labs hire out their services;
- Large cities usually have well-equipped laboratories and trained personnel;
- Some industries hire out their personnel and lab facilities, on the side, to do testing work;
- Universities generally have facilities and trained personnel.

Flow Measurement. Flow measurements should be taken at the same locations and times that water quality samples are taken. The U.S. Department of Interior, Bureau of Reclamation, has published a handbook detailing flow measurements entitled, Water Measurement Manual.

V-notch weirs, built to standard dimensions can be used to estimate flows. Parshall flumes are also available. These devices are not very portable and should be installed for an entire season. Conversion tables are used to give actual flow values. Recorders may be fitted to these devices.

Volumetric methods (bucket and stopwatch method) are excellent for measuring small flows from pipes.

Flows from wells may be closely estimated, using the California pipe method explained in the Water Measurement Manual.

A final method is to use flow meters, which can determine velocity in open channels.

4.2.3 Analysis of the Water Quality Impacts of Irrigation Returns

Evaluation of the water quality impacts of return flows must take into consideration:

- Irrigation hydrology;
- Quality of supply water, return flows, and in-stream flow;
- Agricultural practices;
- Natural conditions;
- Downstream water uses.

These factors may then be used to define pollutant problems in an irrigated region.

Irrigation hydrology is important since it is the system of diversions and returns that causes the degradation of many Western waters. Some of this degradation is the necessary and direct result of consumptive use concentrating salts. Unnecessary salt pickup and the return of other pollutants is the result of inefficiencies in the irrigation system, however.

Water quality of return flows should be considered in terms of the impact they have upon the stream. This means knowing the stream water quality, as well as the quality of the return flow. Particular attention should be paid to the quality of a return flow as it relates to agricultural practices and natural conditions.

Analysis of Parameters Associated with Leaching.

Salinity and nitrate concentrations may increase as a result of the inflow of lower quality seep or tributary inflows. Base level salinity increases resulting from consumptive use should be analyzed. Locating areas contributing high pollutant loads may be used to define potential problem areas. Figures 4-7 and 4-8 show analyses of data for water quality and correlation to mapped data.

Analysis of Parameters Associated with Surface Runoff

Surface runoff carries sediment and phosphorus as well as some pesticides. Since sediment and phosphorus are carried by surface returns, tributary inflow should be the only source of these pollutants. Some problems occur with analysis of sediment and phosphorus since these constituents are not dissolved and thus, are not conservative. In addition, it may be that a program does not locate all sources.

Sediment may settle out in the stream, or be picked up from stream bottom sediment left during a low flow period. Bank erosion may be a significant sediment source during high flow periods.

Phosphorus associated with irrigation tailwater tends to be attached to soil particles. As a result, it is subject to settling and pickup in much the same way as sediment.

Computer Simulation of Irrigation Return Flow

The U.S. Bureau of Reclamation has developed a computer model for simulating subsurface irrigation return flows. The benefits to be derived from using such a model are obvious. If a system can be modeled with sufficient

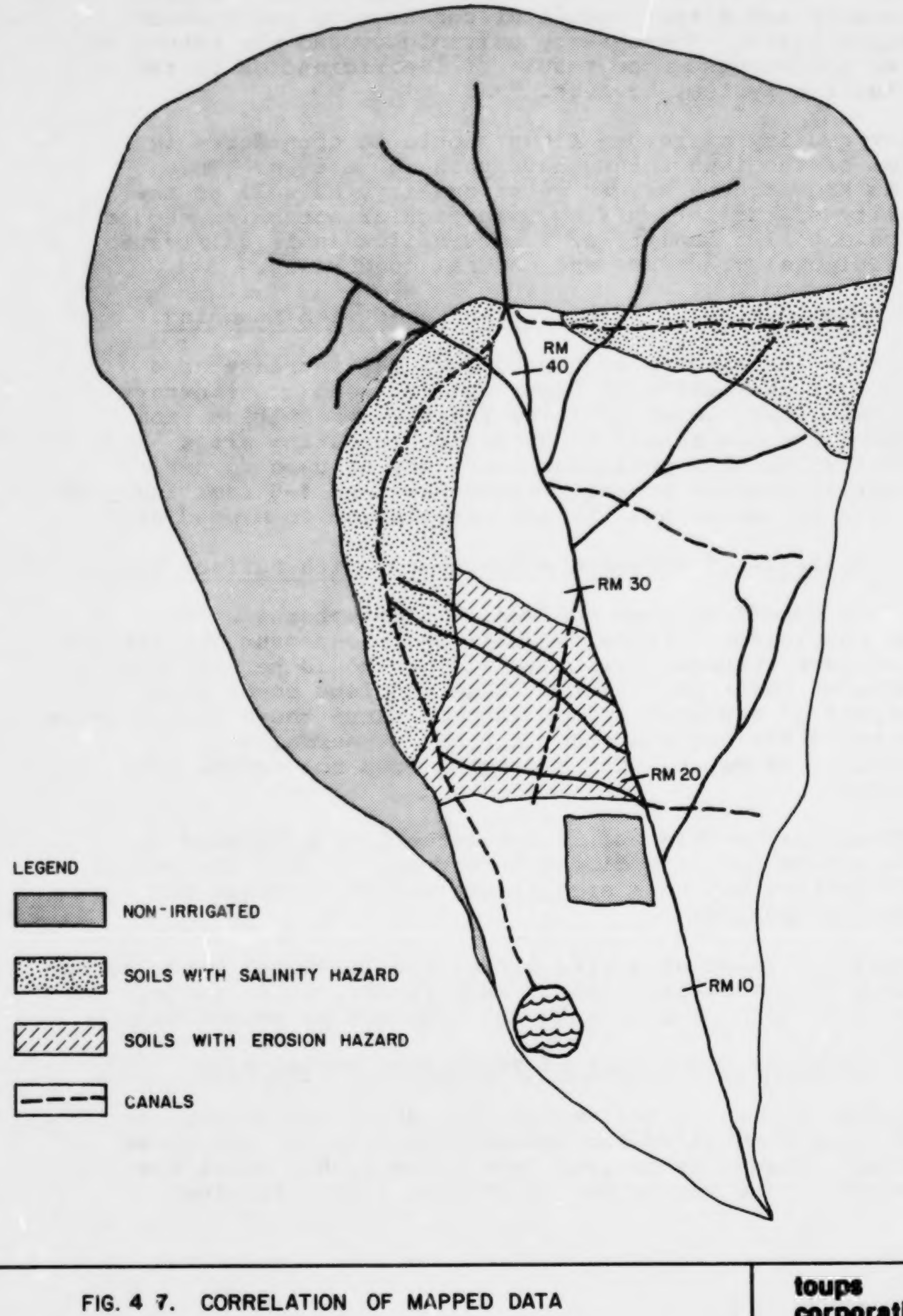
RM 40
RM 30
RM 20
RM 10
LEGEND
NON-IRRIGATED
SOILS WITH SALINITY HAZARD
SOILS WITH EROSION HAZARD
CANALS

FIG. 4 7. CORRELATION OF MAPPED DATA

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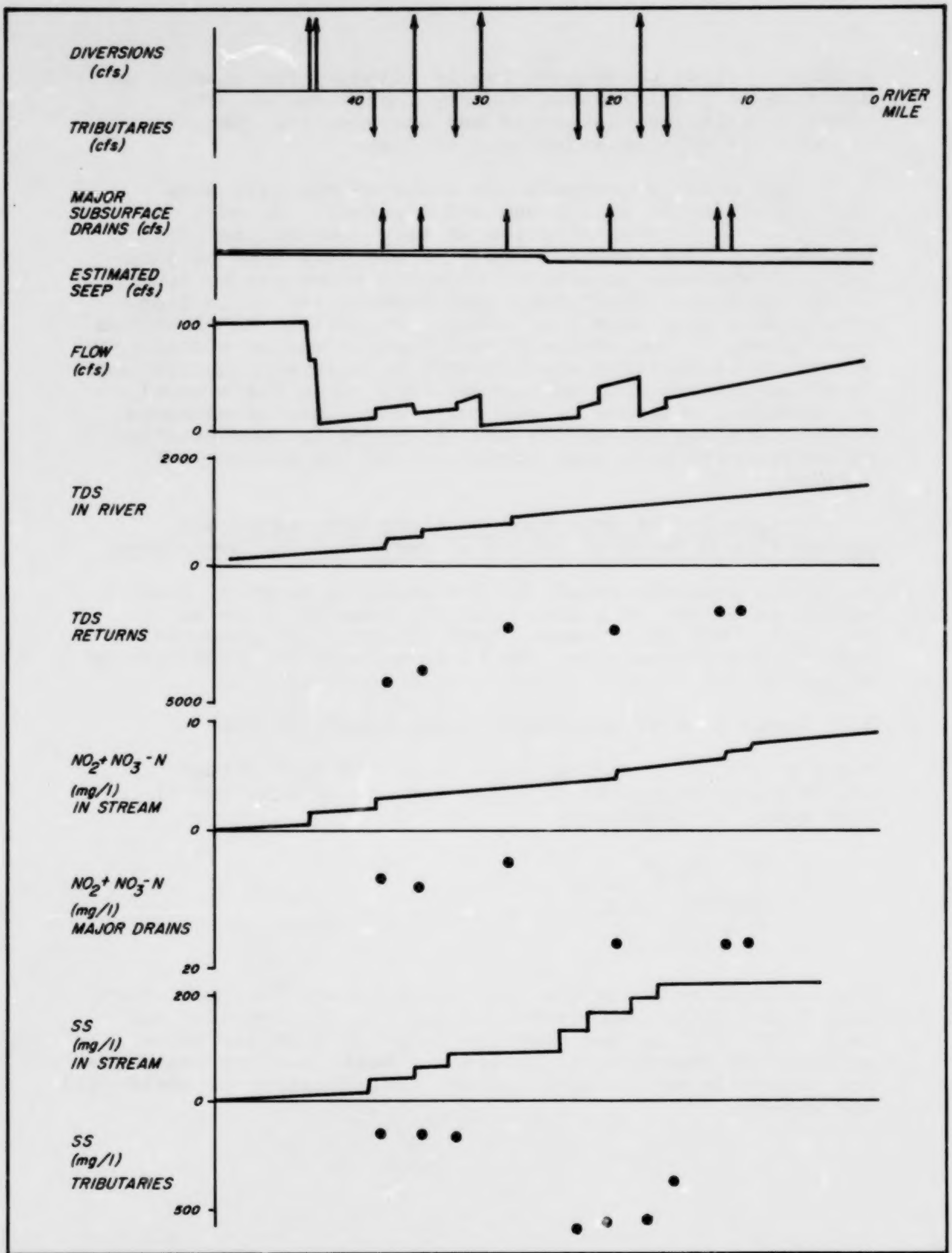

FIG. 4-8. WATER QUALITY ANALYSIS

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accuracy, input parameters can be adjusted for changes in practice to predict water quality improvements. The model is quite sophisticated and can simulate chemical changes, as well as hydrologic loading.

While the model represents the state of the art, some limitations exist on its use and accuracy. As with any model, it is a simplification of very complex, natural processes. Such natural processes are very hard to simulate. Tremendous amounts of time and money can be spent in calibration. Input data requirements are quite high. Even with a high degree of effort, confidence in predicted results may be low, and predicted results may be exceedingly sensitive to an input which cannot be precisely quantified. Costs associated with collecting input data for a model, calibration, sensitivity analysis, etc., may be enormous. These costs may exceed the cost involved in demonstration projects, with much less confidence in the accuracy of results.

Evaluation of Pollutant Problems Associated with Return Flow in Terms of Potential Benficial Use Downstream

Pollutant problems should be evaluated in terms of downstream water use if a water quality benefit is to be realized. For this reason, both existing and potential uses of downstream water should be evaluated. Local stream standards should also be taken into consideration.

4.3 WATER QUALITY REQUIREMENTS FOR BENFICIAL USES

Water pollution emanating from irrigated agriculture may degrade the quality of water for one or more beneficial uses, including:

- Irrigation
- Livestock water;
- Domestic supply;
- Fishing;
- Recreation.

The value of reducing the irrigation return flow pollution load lies in the improvement of quality for one of these uses. It is often not possible to place a dollar value on expected improvements, however. Water quality standards are generally established through consideration of beneficial use aspects.

4.3.1. Irrigation Water

Salinity. Dissolved solids are the pollutants of major concern in irrigation waters. The various cations and anions increase osmotic pressure. In the soil solution, water may contain five to ten times the salinity of irrigation water. High osmotic pressure of the soil solution can result in reduced yields or the requirements to grow tolerant crops.

The degree of harm caused by various salinity levels and by various ion concentrations is highly dependent upon crop, soil, and management practices. Irrigation waters may be classified according to the diagram presented in Figure 4-9. The suitability of these waters for various crops and soils is presented in Table 4-1. It should be noted that the information presented represents guidelines and that in practice waters of poorer quality are often used. The use of these lower quality waters may come at the expense of reduced yields, increased management requirements, or salt buildup in the soil, however.

Relative salt tolerance for several crops is displayed in Table 4-2. It should be noted that the table is based on the conductivity of the soil moisture extract which may easily be five times the conductivity of applied water, due to the concentration of salts resulting from consumptive use. It should also be noted that the table displays only relative tolerance, and that in practice soil moisture salinity may exceed these levels. Comprehensive up-to-date information on crop tolerance to salinity is presented by Maas and Hoffman (1977), Ayers (1977), and Christiansen, Olsen, and Willardson (1977).

Sodium. The most common method displaying the relative sodium hazard is the Sodium Adsorption Ratio (SAR):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where Na^{+}, Ca^{++}, and Mg^{++} are expressed in me/l.

The SAR may be used to determine the quality of water for irrigation as is displayed in Table 4-1.

Sodium problems mainly occur in soil structure, infiltration, and permiability rates. These problems are especially pronounced on clays, especially swelling clays.

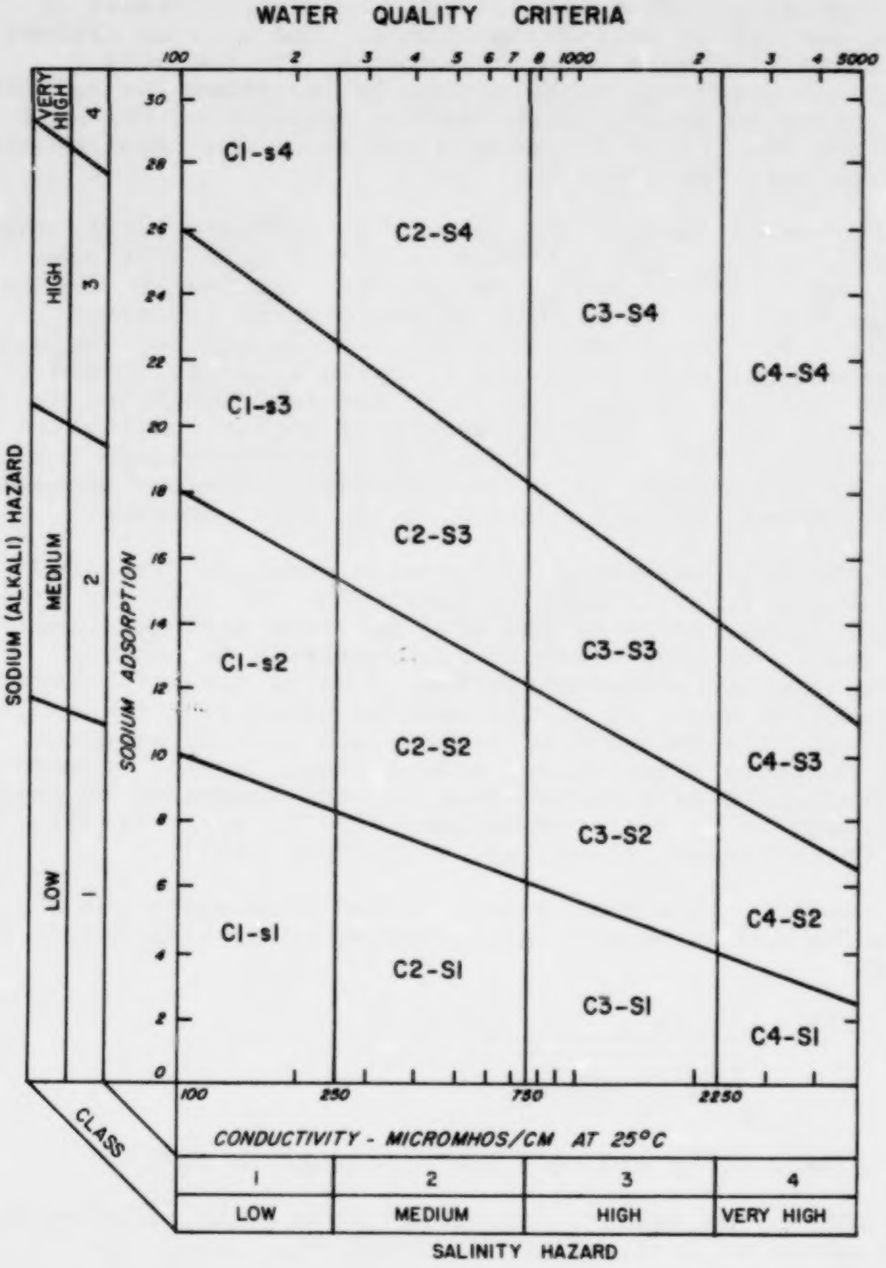

FIG. 4-9. DIAGRAM FOR THE CLASSIFICATION OF IRRIGATION WATERS [A]

[A] USDA, 1954

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TABLE 4-1 SUITABILITY OF WATERS FOR IRRIGATION*

Class	Salinity or Conductivity	Sodium-Adsorption Ratio+
Low 1	Low-Salinity Water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.	Low-Sodium Water (S1) can be used for irrigation of almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone fruit trees and avocados may accumulate injurious concentrations of sodium.
Medium 2	Medium-Salinity Water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.	Medium-Sodium Water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.
High 3	High-Salinity Water (C3) cannot be used on soils with restricted damage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.	High-Sodium S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management-good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.
Very High 4	Very High Salinity Water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.	Very High Sodium Water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

* Adapted from U.S.D.A., 1954.

+ Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be taken into account in the use of C1-S3 and C1-S4 waters. For calcareous soils with high pH values or for noncalcareous soils, the sodium status of waters in classes C1-S3, C1-S4, and C2-S4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when C2-S3 and C3-S2 waters are used.

TABLE 4-2 RELATIVE SALT TOLERANCE OF VARIOUS CROP PLANTS (a)

Relatively Nontolerant EC x 10^3 2.0-4.0(b)	Moderately Salt Tolerant EC x 10^3 4.0-6.0(b)	Relatively Salt Tolerant EC x 10^3 6.0-8.0(b)	Highly Salt Tolerant EC x 10^3 8.0-12.1(b)
FIELD CROPS			
Field beans	Sorghum(grain)	Cotton	Barley(grain)
Cowpeas	Corn(field)	Rye(grain)	Sugar Beet
	Castorbean	Wheat(grain)	Rape
	Soybean	Oats(grain)	
		Rice	
FORAGE CROPS			
White clover	Tall fescue	Wheat-grasses	Alkali sacaton
Alsike clover	Meadow fescue	Sudan grass	Bermuda grass
Red clover	Orchard-grass	Sweetclover	Barley(hay)
Ladino clover	Millet	Alfalfa	Rhodesgrass
Crimson clover	Sour clover	Ryegrass	Blue grama
Rose clover	Birdsfoot trefoil	Rye(hay)	Panicgrass
Burnet clover		Wheat(hay)	
		Oats(hay)	
VEGETABLE CROPS			
Lima bean	Tomato	Garden beet	Asparagus
Green bean	Broccoli	Kale	
Celery	Cabbage	Spinach	
Radish	Pepper	Okra	
	Lettuce		
	Sweet corn		
	Onion		
	Pea		
	Watermelon		
	Cantaloupe		
	Squash		
FRUIT CROPS			
Pear	Olive	Pomegranate	Date Palm
Apple	Grape	Fig	
Orange			
Grapefruit			
Plum			
Apricot			
Peach			
Strawberry			
Lemon			
Avocado			

(a) U.S. Department of Agriculture, 1954.

(b) Conductivity of saturation extract from the soil, expressed as milli-mhos/em at 25°C.

Where sodium problems exist, calcium, calcium producing amendments, sulfur, or acids may be added to the soil in an effort to exchange calcium for sodium in the soil and leach sodium from the root zone.

Chlorides. Chlorides may be harmful to certain crops. Particularly sensitive are fruit crops - citrus, avocado, grapes, and certain berries. Detriment to these crops may occur through either chloride levels in the soil or foliar absorption of sprinkler-applied water. Chloride tolerance is highly variable upon crop type.

Chlorides are the most soluble anion. While others may precipitate in the soil, chlorides tend to remain in the system and concentrate proportional to water useage.

Sediment

The effect of sediment is highly dependent upon irrigation method. Sediment is detrimental for sprinkler or trickle irrigation since it may cause clogging and wear. Fine sediment may be benficial for surface irrigation of sandy soils, since the fines trapped in the sand can reduce infiltration making the water advance down the furrow faster.

Nitrates. Nitrates are generally beneficial in irrigation water.

Phosphorus. Phosphorus is beneficial in water to be used for irrigation.

Pesticides. Pesticides are detrimental to water to be used for irrigation.

4.3.2 Livestock Water

Dissolved Solids

The quality of water required for livestock is dependent upon the type of animal and the acclimatization of the animal to water of a particular dissolved solids level. Dissolved solids in livestock water are primarily detrimental because they impair the osmotic process. General guidelines for livestock water are presented in Table 4 3.

TABLE 4-3 GUIDE TO THE USE OF SALINE WATERS FOR LIVESTOCK AND POULTRY

(Committee on Water Quality Criteria 1972)

Total Soluble Salt Content of Waters (mg/l)	Comment
Less than 1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.
3,000-4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality, and decreased growth, especially in turkeys.
5,000-6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Nitrates and Nitrites

Nitrate and nitrite may cause poisoning of livestock. The Committee on Water Quality (1972) has recommended that

NO_3-N plus NO_2-N content in drinking waters for livestock and poultry should be limited to 100 mg/l or less, and the NO_2-N content should be limited to 10 mg/l or less.

Pesticides

While there were no reported cases of livestock toxicity resulting from pesticides in water, a potential problem exists (Committee on Water Quality Criteria, EPA, 1972).

4.3.3 Domestic Use

Several physical (aesthetic), chemical, and bacteriological standards are placed on water for domestic supply. Irrigation return flows and receiving waters may not meet these standards because of diminished physical and chemical quality. Table 4-4 displays recommended and mandatory limits for many constituents.

Physical parameters impairing water quality are turbidity and odor. These properties are generally treated in conventional water treatment. Surface irrigation systems which return tailwater to the river can increase turbidity in the river.

Chemical characteristics of drinking water must meet many criteria in order to be considered good. Needless to say, many water supplies do not meet recommended limits. Various cations and anions associated with irrigation return flows, as well as total dissolved solids levels, have either recommended limits or mandatory limits.

Total dissolved solids levels increase as a result of irrigation. There are no mandatory limits for total dissolved solids, since low TDS waters are totally unavoidable in many areas. Dissolved solids are primarily an impairment to taste, although sodium may be detrimental to those who are on restricted sodium ditets.

Nitrates plus nitrites are limited to 10 mg/l as N in the EPA Interim Primary Water Standards. This has been established as a safe amount. Levels above this have been linked to methemoglobinemia in infants.

Irrigation leachate can be of significantly higher nitrate concentrations than applied water. Although returns of seepage water rarely cause surface water to contain more than 10 mg/l NO_3-N+NO_2-N, ground water may contain this much or more. Irrigation returns may contribute to the loading of high nitrate waters to the ground water, especially when large amounts of fertilizer are used on sandy soils.

TABLE 4-4 EPA WATER QUALITY STANDARDS FOR DISCHARGE TO GROUND WATERS UTILIZED AS A DRINKING WATER SUPPLY

Constituent	Maximum Allowable Level (a) National Interim Primary Drinking Water Standards	Proposed National Secondary Drinking Water Standards
Chemical		
Arsenic (As)	0.05	-
Barium (Ba)	1.0	-
Chloride (Cl)	-	250.
Chromium (Cr)	0.05	-
Copper (Cu)	-	1
Fluoride (F)		
53.8°F	2.4	-
58.4-58.3	2.2	-
63.9-70.6	1.8	-
70.7-79.2	1.6	-
79.3-90.5	1.4	-
Foaming Agents (MBAS)	-	0.05
Hydrogen Ion (pH)(b)	-	6.5-8.5(f)
Hydrogen Sulfide (H_2S)	-	0.05
Iron (Fe)	-	0.3
Lead (Pb)	0.05	-
Manganese (Mn)	-	0.05
Mercury (Hg)	0.002	-
Nitrate (NO_3 as N)	10.0	-
Selenium (Se)	0.01	-
Silver (Ag)	0.05	-
Total Dissolved Solids (TDS)	-	500.
Zinc (Zn)	-	5
Physical		
Color (b)	-	15
Corrosivity	-	non-corrosive
Odor(b)	-	3
Turbidity	1(d)	-
Radionuclides(c)		
Radium 226 plus 228 (c)	5	-
Gross Alpha Activity(c)	15	-
Gross Beta plus Photon Activity	(e)	-

TABLE 4-4. EPA WATER QUALITY STANDARDS FOR DISCHARGE TO GROUND WATERS UTILIZED AS A DRINKING WATER SUPPLY (CONTINUED)

	Maximum Allowable Level (a)	
Constituent	National Interim Primary Drinking Water Standards	Proposed National Secondary Drinking Water Standards
Pesticides		
Endirin	0.002	-
Lindance	0.004	-
Methoxychlor	0.1	-
Toxaphene	0.0005	-
Chlorophenoxys		
2,4-D	0.1	-
2,4,5-TP Silver	0.01	-

(a) Expressed as milligrams per liter unless otherwise noted.
(b) Expressed as units.
(c) Expressed as pico-Curries per liter.
(d) May be 5 turbidity units or less for certain conditions.
(e) Shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year.
(f) Limits of allowable range.

The anions chloride and sulfate also have recommended levels. Sulfate can cause distress in the lower digestive tract of humans and animals. Chlorides impair the taste of water when levels reach approximately 250 mg/l.

Dissolved solids and nitrates can place a definite impairment on water quality for downstream domestic use.

Pesticides are detrimental to domestic use. Specific criteria are given in the references.

4.3.4 Fisheries

Water quality and stream hydrology limit the types of fish which can live in a stream. Stretches of a river which are periodically dried up cannot support significant fish life. The water quality necessary to support a suitable fish species diversity has the following proposed limits: (McKee and Wolf, 1963):

1. Dissolved oxygen not less than 5 mg/l;
2. pH approximately 6.7 to 8.6 with an extreme range of 6.3 to 9.0;
3. Specific conductance at 25°C, 150 to 500 mmho with a maximum of 1000 to 2000 mmho permissible for streams in western alkaline areas (Note: total dissolved solids (mg/l) generally equals about 0.7 x specific conductance);
4. Free carbon dioxide not over 3 cc per liter;
5. Ammonia not over 1.5 mg/l;
6. Suspended solids such that the millionth intensity level for light penetration will not be less than 5 meters.

These should not be interpretted as maximum sublethal levels. Rather, they are conditions favorable to a good mixed warm water fish population.

Of the pollutants associated with irrigation returns, sediment and temperature are probably most detrimental to fish life. Sediment can cover the bottom of a stream, burying fish eggs and covering the benthic invertebrates which serve as food to many species of fish.

While many streams affected by irrigated returns have significant aquatic life, many of these fish are carp and other "trash fish." The proliferation of these fish is mostly due to their tolerance to high temperature water. This high temperature water is usually the result diversions drying up a river and fish having to survive in the remaining pools. Habits of the carp generally prohibit their coexistence with other fish species.

4.3.5 Recreation

Recreational water use includes swimming, boating, and aesthetic enjoyment. Water quality requirements of swimmable waters are:

- They must be aesthetically enjoyable, i.e., free from obnoxious floating or suspended substances, objectionable color, and foul odors;
- They must contain no substances that are toxic upon ingestion or irrigating to the skin skin or human beings; and
- They must be reasonably free from pathogenic organisms (McKee and Wolf, 1963).

Requirements for boating are mostly aesthetic.

5.0 IRRIGATED AGRICULTURAL PRACTICES AND POLLUTION CONTROL OPTIONS

The Environmental Protection Agency has defined best management practices as follows:

> "the term best management practices (BMP) means a practice or combination of practices that is determined by the state (designated areawide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality roles."

The emphasis is clearly to reduce pollution at the source rather than to treat pollution after it occurs.

For irrigated agriculture, improved irrigation practices are the primary method of reducing pollution load at the source. Alteration of conveyance systems, return flow systems, and improved management of tillage practices and chemical use may also be helpful.

Several practices are presented in this section. These practices can be related to several broad categories:

- Delivery Systems
- Application Systems
- Return Flow Systems
- Chemical and Land Use Management

5.1 DELIVERY SYSTEMS

5.1.1 Conveyance Systems

Major losses of water occur through seepage from conveyance facilities. On a national basis, delivery losses may be in the range of 20 to 25 percent of the total diversion of surface water (Hagen 1967; Houk 1956).

Seepage losses may or may not represent a pollutant loading mechanism. In most areas, especially where soils are alluvial, that portion of water lost from the delivery system does not become degraded as it flows to the ground water. In a few areas, however, geologic conditions (saline soils or subsoils) may result in a significant salt pickup by seepage waters. This has been shown to be especially significant in the Grand Valley of Colorado (Skogerboe & Walker, 1972). Seepage losses may be detrimental when they result in non-beneficial consumptive use and wet areas, as well.

Non-beneficial consumptive use of seepage waters occurs along phreatophyte lined canals, in wet areas below canals, and in areas where canal or ditch seepage otherwise results in high water tables. While the amount of water lost through these mechanisms (and the resultant concentration of salts) may not be large, it is avoidable.

Delivery systems can be improved by lining open ditches or conversion to pipelines. Slip form concrete lining and PVC pipe has made upgrading smaller ditches feasible for water conservation. Most irrigated areas have contractors specializing in these operations, and price lists are readily available.

Concrete slip form lining and pipelines are the most popular permanent ditch upgrades. Other methods of reducing seepage include: asphalt lining, flexible membrane lining, chemical sealants, bentonite, compacted earth, and corrugated metal.

It is difficult to evaluate the effect which canal lining would have on pollution control. While reduction in seepage can be predicted, the corresponding decrease in salt loading is hard to evaluate (Skogerboe & Walker, 1972).

Seepage losses can be reduced to 0.03-0.06 m^3/m^2/day (0.1-0.2 ft^3/ft^2/day) with a hard surface lining such as concrete. Losses in unlined canals are highly dependent upon soil conditions, but can be expected to be significant in all but the more impermeable soils.

Canal lining is limited by high costs of materials and labor. In addition, many irrigation, canal, and ditch companies own senior water rights to specified rates of flow. Conveyance losses were considered in the granting of the rights. With a sufficient right for irrigation and losses, no incentive toward water savings is apparent. While many on-farm ditches are lined, canals and laterals are often incorporated among several users. These water users would often rather spend money on their own farm than on the incorporated canal.

5.1.2 Flow Measurement

In order to achieve efficient irrigation, farmers must know how much water they are applying. Flow measurement of diversion and tailwater is necessary to determine the average amount of water applied to the field. Without water measurement there cannot be water management.

Flow measurement is currently inadequate in most areas. Where devices exist, they are often in poor condition and may not be properly read. This condition exists because excess water is guaranteed by right or the water is inexpensive in comparison to labor and equipment costs. Deep seepage losses have been found to be 50 percent of applied water in the Grand Valley, Colorado and in the Snake River Valley, Idaho (Skogerboe 1975; Carter 1972).

Benefits to be derived from good flow measurement are considerable. With flow measurement, the amount of water applied can be easily calculated. Flow measurement is necessary to apply the proper amount of water. In addition, good flow measurement insures fair distribution of water among farmers preventing hard feelings during dry years.

5.2 IRRIGATION APPLICATION SYSTEMS - DESCRIPTION

There are three main methods of distributing water on the farm: furrows, flooding, and sprinklers. Furrow irrigation is used on approximately 54 percent of the irrigated land, flooding on around 30 percent and sprinklers on about 15 percent. Lesser used methods of irrigation include subirrigation and trickle irrigation. Subirrigation is used on less than 1 percent of the irrigated land. Trickle irrigation is becoming popular on tree and bush crops, although currently used on less than 1 percent of the irrigated land. Each year, sprinkler and trickle irrigation show an increased percentage of total irrigated acreage.

Each irrigation method has limitations in terms of crop, topography, soil permeability, and water supply. In addition, each irrigation method has characteristic return flow mechanisms. Figure 5-1 illustrates several irrigation methods.

5.2.1 Furrow Irrigation

Furrow irrigation is the most widely used form of irrigation. Furrow irrigation is popular because it involves small capital investment, is well suited to growing row crops, and may be used with most soils. Furrow irrigation is equally suited to delivery characteristics of wells or ditches.

Furrow irrigation may be used in soils having final water infiltration rates from 0.25 to 7.62 centimeters/hour (0.1 to 3.0 inches per hour). Extreme irregularity of the water infiltration rate across a field makes furrow irrigation difficult and inefficient. Topography is significant in furrow irrigation and efficiency can suffer greatly when slopes are irregular. Land forming is often required in order to obtain correct slope.

Length of run is perhaps the most important factor in determining potential efficiency with furrow irrigation. The length of run and the number of furrows to be irrigated by the available stream are the essential design and operational factors, since the other factors determining water distribution such as soil infiltration capacity may be uncontrollable. Excessive length of run is used on most fields to reduce labor requirements. Excessive length of run can greatly reduce irrigation efficiency.

The various types of furrow irrigation systems will be described and discussed separately, since each has specific characteristics which make general discussion insufficient.

Furrows

Furrow irrigation is characterized by slight slope, straight alignment, large capacity, long reach, and use with row crops (Marr 1967). These systems are widely used and are a familiar sight in most irrigated regions. Furrows are essentially straight and may be from 0.1 to 0.8 kilometer (1/16 to 1/2 mile) long, depending upon other conditions.

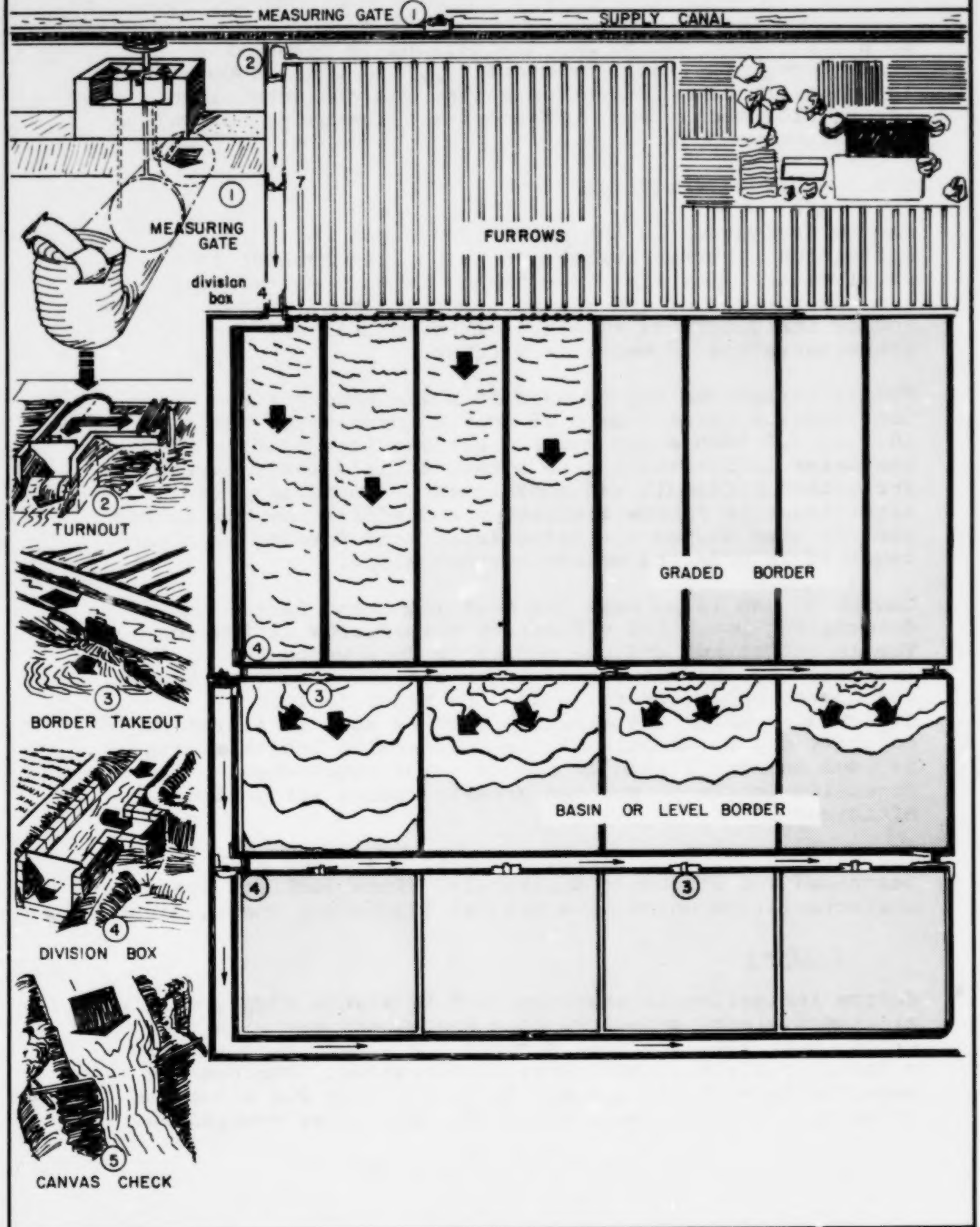
MEASURING GATE ①
SUPPLY CANAL
②
7
①
MEASURING GATE
division box
4
FURROWS
② TURNOUT
④
GRADED BORDER
③
③ BORDER TAKEOUT
BASIN OR LEVEL BORDER
④
③
④ DIVISION BOX
⑤ CANVAS CHECK

FIG. 5-1. IRRIGATION METHODS [A]

[A] Redrawn from SCS Engineering Manual, Ch. 15, Irrigation.

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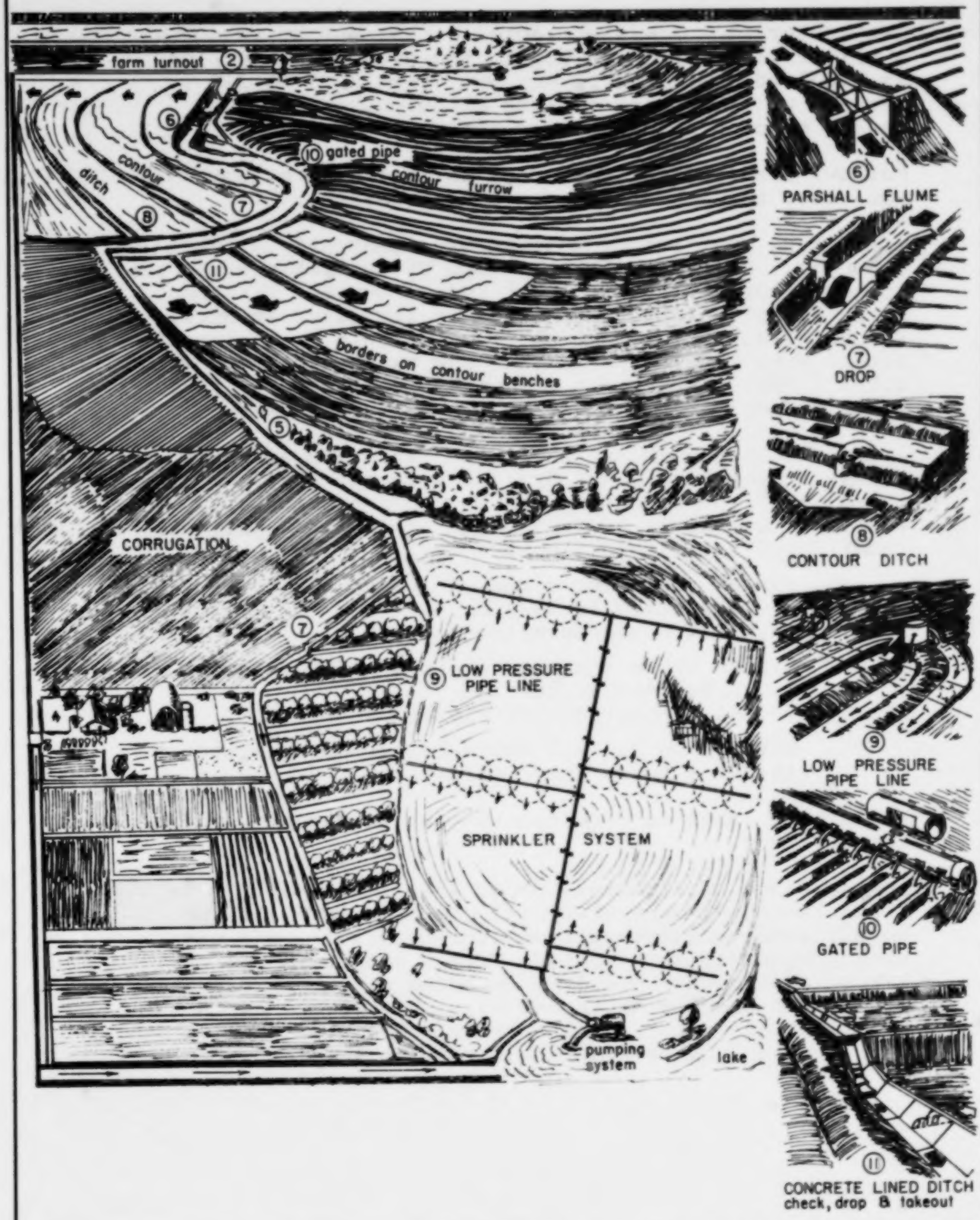
farm turnout ②
⑥
⑩ gated pipe
contour furrow
contour
ditch
⑦
⑧
⑪
borders on contour benches
⑤
CORRUGATION
⑦
⑨ LOW PRESSURE PIPE LINE
SPRINKLER SYSTEM
pumping system
lake
⑥
PARSHALL FLUME
⑦
DROP
⑧
CONTOUR DITCH
⑨
LOW PRESSURE PIPE LINE
⑩
GATED PIPE
⑪
CONCRETE LINED DITCH
check, drop & takeout

FIG. 5-1. (cont.). IRRIGATION METHODS [A]

[A] Redrawn from SCS Engineering Manual, Ch. 15, Irrigation.

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Topography is a limiting factor in the use of furrows. A slight slope from the top to the bottom of the field is required. This slope may vary from 0.05 to 2.0 percent under best conditions although slopes of up to 4.0 percent are sometimes used (Marr 1967).

Furrows are used for row crops including corn, cotton, potatoes, sugar beets, beans, and vegetables.

Irrigating with furrow systems is essentially a full-time job. The size of the stream of available water is an important element in labor requirements. With small, streams, only a few furrows can be irrigated at once. Large streams allow more furrows to be in operation at one time. Marr (1967) states that one man can manage around 0.057 m^3/sec (2 cfs) for low intake soils and 0.198 to 0.227 m^3/sec (7 to 8 cfs) for high intake soils.

Actual labor inputs are highly variable and appear to be mainly affected by water availability and cost. Furrow irrigation labor requirements may vary considerably with field layout and water management practices. Estimates of labor input for irrigation alone are:

- Siphon tubes and dirt-head ditch 1.5-5.7 hours/hectare/irrigation (0.6-2.3 hours/acre/irrigation)
- Siphon tubes and concrete-head ditch 1.0-4.2 hours/hectare/irrigation (0.4-1.7 hours/acre/irrigation)
- Gated pipe 0.7-2.7 hours/hectare/irrigation (0.3-1.1 hours/acre/irrigation)

Additional labor is required to pull in ditches, form furrows, etc.

Lowest labor requirements occur when length of run is excessive on an otherwise well planned field. These lowest labor requirements are the result of only minimal water conservation efforts. With a proper length of run, labor requirements could be expected to be approximately double the minimum expressed here. Improvements in the distribution system, particularly gated pipe or concrete head ditches, can greatly reduce labor requirements.

Investment is generally considered to be minimal with furrow irrigation. Land forming will not be excessive in suitable areas. The major capital cost would be expected to be lateral construction. Annual maintenance costs include furrow forming and ditch maintenance as well as irrigation labor.

Corrugation Systems

Corrugations are similar to furrows except that they are smaller in size. The smaller furrow streams associated with corrugations allow them to be used on steeper lands without erosion hazard. Either a small, continuous stream or a larger, intermittent stream may be used for corrugations.

Corrugations may be used on steeper slopes due to the smaller furrow stream. The general direction of irrigation remains downhill. Optimum slopes are 2 to 4 percent for machine harvested close-grown crops; 2 to 4 percent for pasture; and 1 percent for row crops (Marr 1967). Allowable slopes may be greater, up to 12 percent for close-grown crops and pasture, on suitable soils.

Soils with a final infiltration rate of up to 2.54 centimeter/hour (1-inch per hour) may be irrigated by corrugations. Corrugations are especially suited for soils having low final infiltration rates, down to 0.25 centimeter/hour (0.1 inch per hour).

Corrugations are commonly used to irrigate close-grown crops and pasture. Alfalfa and small grains are likely to be irrigated by corrugations. Some small row crops may also be irrigated by this method.

Contour Furrow Irrigation

As the name indicates, contour furrows run across-slope. Contour furrows may be used for irrigation of orchards, vineyards and bush crops on uneven terrain with slopes less than 5 percent. Stability against erosion and breach by the furrow water is a major concern. In areas of intense rainfall, water may not drain off sufficiently resulting in breaching and gully erosion.

Perennial crops of trees and tree-like plants hold the soil and may be grown on the steeper slopes with contour furrows. This method is applicable to row crops only when slopes are slight.

5.2.2 Border Strip Flooding

Border strip flooding is a controlled process. The area to be irrigated is surrounded by a dyke. The land inside the dyke is made as planar as possible with a slight slope from the top to the bottom of the field. Alfalfa, pasture, and other close-grown crops are commonly irrigated by this method, although it is possible some row crops could be irrigated by borders.

Border strips usually require considerable land grading. Border strips may be 10 to 20 meters (30 to 60 feet) wide, and 100 to 400 meters (330 to 1,320 feet) long. Down slopes may be from 0.15 to 1.5 percent with 0.2 to 0.3 percent being ideal. Cross slopes should be less than 0.2 percent. Border strips are then restricted to fairly flat areas, although with land grading there can be small differences in elevations from one border to the next. In areas with less permeable soils, the longer borders can be used. Surface runoff is generally less than with furrow irrigation. Because the entire surface is wetted, close growing crops are used and the slope is carefully graded, streams large enough to obtain good distribution may often be used without an excessive erosion hazard.

5.2.3 Level Basin Flooding

In level basin flooding, the entire amount of water is applied quickly and ponded until adsorbed. This method requires flat bottom basins and a large intermittent water supply. It can be effective with a wide variety of soil types. Basins are leveled with laser controlled land leveling equipment.

Level basins have traditionally been used for rice, but recent research has proven them effective for almost any crop. Major requirements are level ground and a very large, available water supply. Average required stream is about 0.007 m^3/sec/hectare (1 cfs/acre), although this varies with soil type. No surface runoff occurs with this method, and excellent distribution may be achieved. Level basin irrigation is becoming increasingly popular, particularly in the southwest.

5.2.4 Wild Flooding

Wild flooding involves the siphoning of water from contour ditches. This method is generally used on steep or rolling irregular land. It is commonly used in the irrigation of pasture and close-grown crops. Wild flooding generally results in poor water distribution and inefficient water use.

5.2.5 Sprinkler Irrigation

Sprinkler irrigation is adaptable to most major farm crops with the exception of rice and orchards planted on steep hillsides. This method provides a relatively high degree of water control when coupled with proper management and design. The sprinkler system should be designed to deliver water at rates less than, or commensurate with, the final infiltration rate. Surface runoff or tailwater is almost completely eliminated using sprinklers and the amount of water leaching through the root zone (leaching fraction) may be reduced with attentive operation. Energy consumption is the major disadvantage to sprinkler irrigation.

There are certain limitations in the use of sprinklers. Wind may cause an unequal distribution of water, and in hot dry climates improper application timing may result in excessive evaporation. Water must be in constant supply and free of debris. Salt deposits on leaves of certain crops may be detrimental if irrigation water is high in dissolved solids, particularly chlorides. Sprinklers are not suited to soils having infiltration rates less than 0.25 centimeters/hour (0.1 inches/hour) (Pair 1966).

There are many types of sprinkler systems varying from fully automated to labor-intensive hand-moved systems. Application efficiencies are generally very high with sprinkler systems. Well designed and operated systems approach 85 percent distribution efficiency. Even application is a major benefit of sprinkler systems. In addition, the amount of water applied can be precisely controlled and monitored. A light application can be made for seed germination, temperature control, or for other reasons.

Evaporation losses from sprinkler systems are greater than with surface systems. Evaporation losses are usually 2 to 8 percent of the total volume, but may be higher in extreme circumstances. Evaporation losses at night are much less and may be disregarded. Evaporation from wet foliage is not an important loss (Frost 1963). A method for determining evaporation loss is presented by Frost (1963).

There are several types of sprinkler systems including: hand moved, side roll, portable solid set, and center pivot. The center pivot has been the most popular by far in recent years. Center pivots offer great labor savings at a reasonable cost. Regular shaped fields are required, and the corners are missed. Typical setup involves the irrigation of 130 acres of a 160 acre quarter section. Water supply should be constant, and problems are sometimes encountered on tight soils. Design inputs such as holding ponds, trash separators, wide tires or built-up wheel tracks can make center pivots adaptable to nearly any situation. The ideal situation is a quarter section of fairly sandy soil served by a well. Energy requirements are dependent upon total water use and total pumping head.

5.2.6 Drip Irrigation

This system was developed in Israel over 15 years ago in an effort to conserve water. Recently it has become quite popular among the orchard growers in southern California. It is adaptable to most soils. Costs have thus far limited its use to high value crops. The system consists of a pump, filter (the complexity of which depends on supply water quality), pressure regulators (depending on field gemoetry), and small diameter plastic pipe running down tree rows with small emitters looping each tree.

The results produced by drip irrigation are a matter of considerable discussion. On-going studies are showing that the savings in irrigation water reported by some is largely related to reduction in evaporation losses from the soil surface prior to establishment of full-crop canopy and root system. Certain specific problems, such as the possible effect of toxic ions on plants have yet to be resolved.

Capital cost estimates vary greatly depending on terrain, supply water quality, and spacing of trees. Recent innovations in the industry coupled with an increased demand have been lowering the cost.

Drip systems eliminate surface runoff, and considerably reduce the quantity of leachate passing out of the root zone. To date, application has been too limited to consider drip systems a general solution to the agricultural pollution problem.

5.2.7 Sub-Surface Irrigation

Water is introduced through open ditches, tile drains or moledrains. The crop is irrigated by artificial manipulation of the groundwater surface elevation by two methods: 1) the groundwater elevation is kept at a depth below the root zone which will not saturate the roots but will allow capillary action to supply the plant with required moisture; 2) groundwater elevation is periodically raised to fill the root zone and then lowered. Use of this method is limited to those areas which have good drainage, no salinity problems, a sufficiently high groundwater elevation or an impermeable layer to permit the formation of a perched water table. Tailwater is not a problem with this method of irrigation. Less than 1 percent of irrigated agriculture is involved with this practice.

5.3 IRRIGATION APPLICATION SYSTEMS - COMPARISON OF RETURN FLOW CHARACTERISTICS

Each method of irrigation has characteristics which make it most suitable to a given set of conditions. In addition, each method of irrigation has its own return flow characteristics. Mitigating measures are often required to utilize an irrigation method where conditions are less than ideal. Such mitigating measures include utilization of holding ponds to alter the time-flow characteristics of the water supply, removal of trash and sediment from water, and land leveling.

Each method of irrigation can be associated with specific return flow characteristics. Management and water measurement play an important role in the actual return flow experienced. Certain alterations of the system may significantly change return flow characteristics. Presented in this section is a discussion of return flow characteristics of the major irrigation methods.

5.3.1 Furrow Irrigation

Both furrow and border strip systems have water distribution problems. These problems are the result of water being applied at the top of the field and flowing down the field, giving the top of the field considerably more opportunity to take in water. Tailwater is essential if the lower end of the field is to receive sufficient water. The design of surface systems limits them to a fairly narrow range of application depths. Light applications for germination or ground softening for harvesting are difficult with these systems.

TABLE 5-1. SUITABILITY OF IRRIGATION METHODS

PRACTICE	WATER SUPPLY	SOIL	TOPOGRAPHY	CROP
Furrow	Continuous or Intermittent	Medium Preferable	0.5 to 3.0%	Row Crop
Border	Intermittent	Medium Preferable	0.5 to 3.0%	Generally used on Close Growing Crop
Level Basin	Intermittent, Large Stream	Fine or Medium	Dead Level	Any Crop
Wild Flooding	Continuous or Intermittent	Fine or Medium Preferable	0.5 to 4.0%	Close Growing Crop
Sprinkler	Continuous	Medium or Coarse Preferable	0.0 to 5.0%	Any Crop
Drip	Continuous or Intermittent	Fine, Medium or Coarse	Any Topography	Tree or Bush Crops
Sub-Irrigation	Intermittent	Impermeable Layer or Water Table at 4 to 12 ft.	0.0	Any Crop

TABLE 5-2. TYPICAL RETURN FLOW CHARACTERISTICS OF IRRIGATION METHODS

IRRIGATION METHOD	DEEP SEEPAGE	TAILWATER
Furrow Irrigation		
Excessive Length of Run	25-60%. Excessive length of run results in poor distribution and excessive leaching of top of field.	3-10%. Excessive length of run reduces tailwater. Bottom of field may be under irrigated.
Proper Length of Run	10-35%. Fairly even distribution can be achieved. Measurement and management are key to good efficiency.	5-20%. Runoff is required to get water to the end of field.
Cut Back Operation Proper Length of Run	10-30%. Very good distribution can be achieved.	3-10%. Cut back operation can greatly reduce tailwater.
Border Irrigation	10-60%. Highly variable depending upon design, soils, measurement and management. Efficient when properly used.	0-10%.
Level Basin	5-30%. Good distribution; highly efficient. Good measurement and management facilitated.	0.
Wild Flooding	15-50%. Highly variable depending upon operations.	0-10%.
Sprinkler	5-30%. Good distribution; good management can result in high efficiency.	0.
Drip	5-25%.	0.
Sub-Irrigation	10-70%. Highly variable	0.

Opportunity time is the time between the advance of the wetting front and the recession of standing water after shut off. The amount of water entering the soil is a function of the opportunity time. Figure 5-2 shows advance and recession curves. Figure 5-2a shows the typical case where the head of the field takes in more water than the lower end. Figure 5-2b shows the ideal case where a nearly equal opportunity time is available. Figure 5-2c shows the advance and recession curves for the case of excessive length of run. Figure 5-3 shows how water is likely to be distributed in the soil. Distribution can be optimized by using an appropriate length of run. Cutting back on the flow may also aid in optimizing distribution.

The amount of water lost to deep seepage and tailwater is highly variable. Deep seepage losses are a function of soil type, length of run, slope, stream size, and management. With tight or medium soils, regular slopes, proper length of run and good management, deep seepage losses from furrow irrigation need not be excessive. Furrow irrigation can be highly efficient with proper design and management. Excessive length of run is a common problem in furrow irrigation. Excessive length of run is common and is the result of a desire to minimize labor requirements at the expense of cheap water. Sandy soils with high infiltration rates are especially susceptable to poor water distribution when length of run is excessive. Excessive nitrate and salt leaching may result. In addition, the over application of water to the top of the field often results in drainage problems.

The amount and quality of tailwater resulting from furrow irrigation is also quite variable. Tailwater volumes resulting from proper length of run and good distribution may be 15 to 20% of the applied water. In practice, tailwater volumes are much less. This is because the length of run is nearly always excessive. Typical tailwater volumes are 5-15% of the applied water. The amount of sediment, phosphorous, and pesticide carried in the tailwater is a function of soil type and furrow stream velocity as well as total tailwater volume.

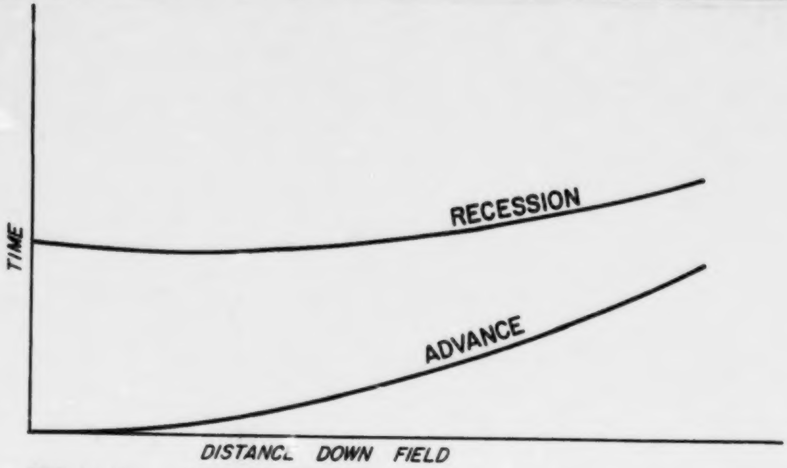

FIG. 5-2. TYPICAL CURVE

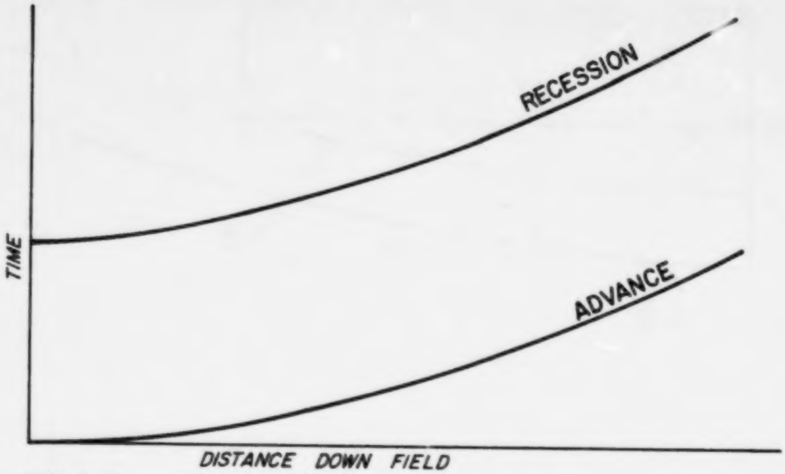

FIG. 5-2. IDEAL CURVE

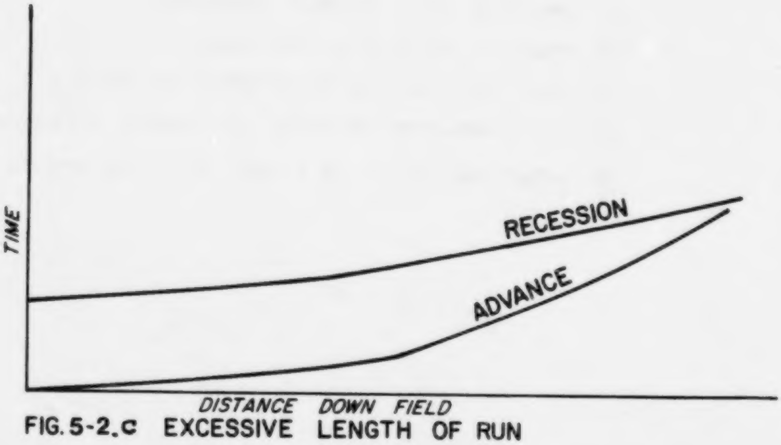

FIG. 5-2.c EXCESSIVE LENGTH OF RUN

FIG. 5-2. ADVANCE RECESSION CURVES FOR SURFACE IRRIGATION

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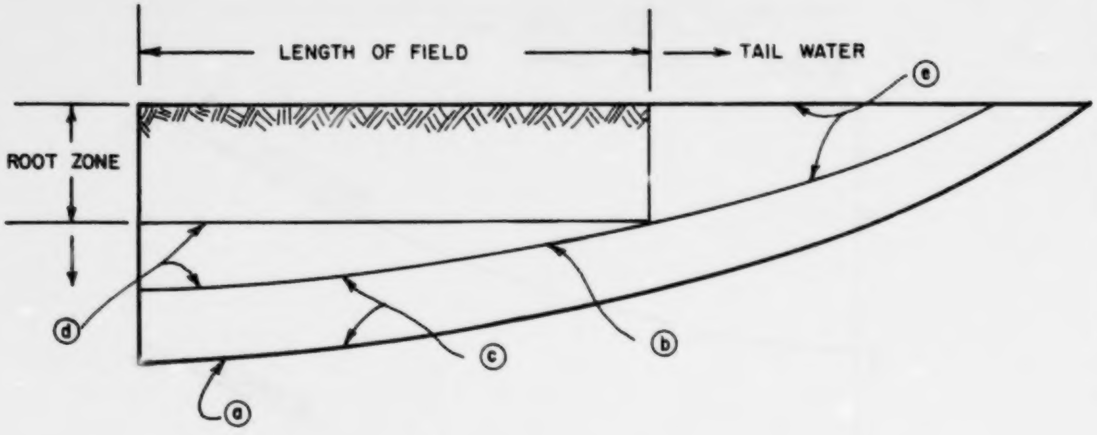
LENGTH OF FIELD
TAIL WATER
ROOT ZONE
ⓔ
ⓓ
ⓒ
ⓑ
ⓐ

ⓐ IRRIGATION DEPTH WITHOUT MANAGEMENT
ⓑ IRRIGATION DEPTH WITH MANAGEMENT
ⓒ OVER IRRIGATION DUE TO IMPROPER APPLICATION
ⓓ OVER IRRIGATION NECESSARY ON SURFACE IRRIGATION
ⓔ WATER THAT COULD BE REUSED WITH TWR SYSTEM

FIG. 5-3. SURFACE IRRIGATION SOIL PROFILE

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Potential for Increased Efficiency

Measures which may reduce return flows include using the proper stream size, cut back irrigation, land leveling, altering the length of run and proper irrigation timing.

Proper Stream Size. Alteration of stream size represents the basic level of system improvement. Because conditions of soil moisture and vegetation vary through the season, a fixed stream size will not provide optimum conditions. The stream size must be varied for changed conditions in soil surface, compaction due to tractor, weather, soil moisture, and crop cover. Stream size is varied by controlling head on input or changing siphon size when water is applied by the ditch siphon method. This represents a labor-intensive situation which is difficult to achieve.

Distribution to furrows by gated pipe offers greater operational controls. Stream size can be optimized such that intake opportunity is more nearly equalized down the field. This can be done by analyzing advance recession curves. Obtaining a proper flow to furrow or border is currently sought by farmers, but further improvement will be likely to come only with labor saving devices which offer better water control combined with on-farm technical assistance.

Cut Back Irrigation. Reducing stream size at the proper time can provide a significant increase in irrigation efficiency by reducing tailwater. Distribution efficiencies may also show increases with cutback operation (Sakkas and Hart 1968). Cut back operation has often been abandoned by farmers due to the increased labor demands incurred.

Cutback operation can result in significant reductions in tailwater. In practice, the furrow stream is reduced as it approaches the end of the field. A smaller stream is used for the remainder of irrigation. Since runoff occurs during the flow of the smaller stream, erosion will be less and, the runoff is likely to contain a lower concentration of sediment. This is true because the erosive tendency of the smaller stream is much less.

Cutback operation is difficult to achieve when water is distributed to furrows by a ditch with siphon tubes. Operational limits exist on the range of head which can be put on the tubes. It is not considered practical by farmers to change tubes to a smaller size during an irrigation. With ditch and siphon tubes, the only practical way of cutting back is to start with two tubes and switch to one after the water reaches the end of the field.

With gated pipe, operational controls allow easy cutback operation either by changing gate openings or by adjusting a valve before the gated pipe.

A problem exists with cutback operation because most farms are delivered a constant flow of water. This problem may be dealt with by two methods: equilization ponds or dividing water between two sets. Equalization ponds can absorb fluctuating outflows with constant inflows. As an alternative, one set can be given a full stream, turned off, and a final set made which irrigates both sets by dividing the water between the two. Water may also be distributed by having a small stream set follow a large stream set as irrigation proceeds across the field.

An automatic cutback system operated by varying head on spiles has been demonstrated. Such a method could provide cutback operation without increase in labor. (Nicholaescu and Kruse 1971).

Cutback operation can greatly reduce the total volume of tailwater. In addition, an improvement in distribution efficiency can be realized. A reduction in concentration of sediment and associated pollutants in the tailwater is also expected. Cutback operation will be widespread only when labor saving devices are combined with on-farm technical assistance.

Slope Modification. Land leveling has been popular with farmers striving to obtain more workable fields. It is necessary to do some land leveling for border irrigation, and there is a significant proportion of furrow irrigated fields which have been leveled. Land leveling is done to remove high and low spots and to obtain a proper slope for irrigation.

Length of Run Alteration. Overly-long irrigation runs can make it difficult to apply sufficient water to the end of the field and causes excessive water application to the top of the field. Shortening irrigation runs can result in increased application efficiency with smaller furrow streams. Farmers are hesitant to divide one long field into two short ones because increased labor is required for irrigation and machinery operation is made much more difficult.

Timing of Irrigation. Improvement in irrigation timing may be effective in reducing return flow volumes. Such improvements in timing may require an educational effort. Irrigation scheduling services offer this educational effort.

5.3.2 Border Irrigation

Border irrigation has many of the same characteristics as furrow irrigation. Water is introduced at the top of the field to flow overland towards the bottom. The combined influences of soil, flow rate, slope, and length of run work in the same manner.

Border irrigation is used with close growing crops. Land leveling is used to create a planar surface, and slopes are nearly always less than 2 percent.

Excessive leaching losses may occur in border irrigation as well as in furrow irrigation. These leaching losses are highly variable depending upon the above mentioned factors.

Tailwater resulting from border irrigation is generally from 0 to 10% of the applied water. Theoretical tailwater volumes may be larger, but excessive length of run is the general case in practice.

The fact that border irrigation is used for close growing crops means that sediment concentrations in the runoff are less than with furrow irrigation. Also contributing to this lesser erosion is the hydraulic nature of border irrigation, i.e., a slow moving sheet of water.

With proper management, border irrigation can be highly efficient. High efficiencies can exist when design (width and length of border) is proper for the soil, slope, and available stream of water. Combined with good operations, high efficiencies can be expected and return flows minimized.

Potential for Increased Efficiency

Several potential improvements to border irrigation exist. The two major improvements include utilization of a concave slope (decreasing slope towards the end of the field) and cut-back irrigation. Both of these changes would serve to make water flow faster over the top of the field and slower over the end of the field. Cut-back irrigation for borders can be conducted in much the same manner as with furrows and will not be discussed separately here.

Concave slopes have been analyzed by researchers who have found that they increased uniformity without complicated cub-back operations which are likely to be abandoned due to the considerable labor involved. Concave slope results, as presented in Table 5-3, indicate better efficiency.

5.3.3 Level Basin Irrigation

Level basin irrigation can be used to achieve extremely high efficiency. Surface runoff is eliminated. Uniform application and the visual impact of ponded water discourage the application of excess water.

5.3.4 Wild Flooding

Wild flooding or contour ditch flooding is generally used for the irrigation of marginal pastureland, or on rolling land used to produce hay. It is used primarily where other methods of irrigation are limited by topography or other economic factors such as short water supply, short growing season, etc.

TABLE 5-3. CONCAVE SLOPE RESULTS ON BORDERS

Powell, Jensen, & King 1972

	CU	Runoff %	Advance Time (min)
Ten Segment Concave	96.6	15.1	345
Four Segment Concave	95.7	15.3	339
Uniform Slope	89.9	17.5	309
Four Segment Convex	79.8	15.3	336

CU = coefficient of uniformity = $1 - \frac{y}{d}$

where

y = average of absolute values of the deviations in depth of water stored from the average depth of water stored

and

d = average depth of water stored

5.3.5 Sprinkler Irrigation

Sprinklers are a very efficient method of irrigation. Surface runoff does not occur with most systems. Distribution efficiencies are often about 85% (Sakkae & Hart 1968). In addition, leaching has been shown to be most efficient under unsaturated conditions.

Management of soil moisture and irrigation timing are the only real limitations to reduction of return flow.

5.3.6 Drip Irrigation

Drip irrigation results in only minimal return flows. Surface runoff does not result from irrigation. Some leaching is necessary, but control is generally good.

5.4 IRRIGATION MANAGEMENT AND EFFICIENCY

Efficient irrigation is the key to reducing return flows. Good irrigation management requires a well designed application system and proper use of that system. Proper water use requires knowledge of crop evapotranspiration, soil-moisture capacity, the amount of water to be applied, and the timing of that application. Good flow measurement is essential for good water management--this is discussed in Section 6.1.

5.4.1 Irrigation Management

Irrigation management is as much an educational process as upgrading of irrigation systems. Items involved in achieving better irrigation efficiencies through better management are:

- Measurement of water deliveries and runoff
- Having a properly designed system
- Using the proper stream size and time of irrigation set to achieve good distribution
- Making the necessary commitment to operations
- Knowledge of crop use and soil-moisture capacity to determine amount and timing of next irrigation.

While increased efficiency can be expected from more intensive management of existing systems, an input of additional labor is required. This additional labor input is almost impossible to achieve under current conditions. Labor-saving devices offer some promise in reducing direct irrigation labor, thereby reducing the time, labor, and money gap between recognition of what should be done and what is actually done.

Irrigation efficiencies currently suffer because inexpensive water can be substituted for the more expensive input of additional labor. This is often due to an over allocation of water. Figure 5-4 shows the relationship between water cost and irrigation efficiency on eleven USBR study sites (USDI-USBR 1973).

5.4.2 Scientific Irrigation Scheduling

Scientific irrigation management services (ISS), also referred to as irrigation management, involves the utilization of a consultant by the farmer in order to schedule irrigations and plan irrigation practice. The service generally involves personal visits to the farm by a trained technician. In the case of sprinkler irrigation, flow measurement of diversions is a must. The basis of the system is the accounting of evapotranspiration requirements and root zone moisture so that irrigations may be predicted. This accounting is generally done using climatic data and computer simulation of inputs and withdrawals from the soil moisture.

Irrigation scheduling services vary as to the amount of service offered. The Bureau of Reclamation has offered three levels of service. The Irrigation Guide is a weekly bulletin sent to the farmer. It gives information on consumptive use, amounts of water to apply and irrigation intervals. No visits are made to the farm. The farm method incorporates visits by a technician, and irrigation data is more detailed. A soil storage coefficient based upon a farm visit is incorporated in the program and based upon the last irrigation date and the expected time of the next irrigation is predicted. The field by field method utilizes soil, crop, and day of last irrigation data for each field together with evaportanspiration data and visits by a technician. This method predicts the optimum day for irrigation in each field. For our discussion, we will describe the components of an intensive irrigation scheduling service.

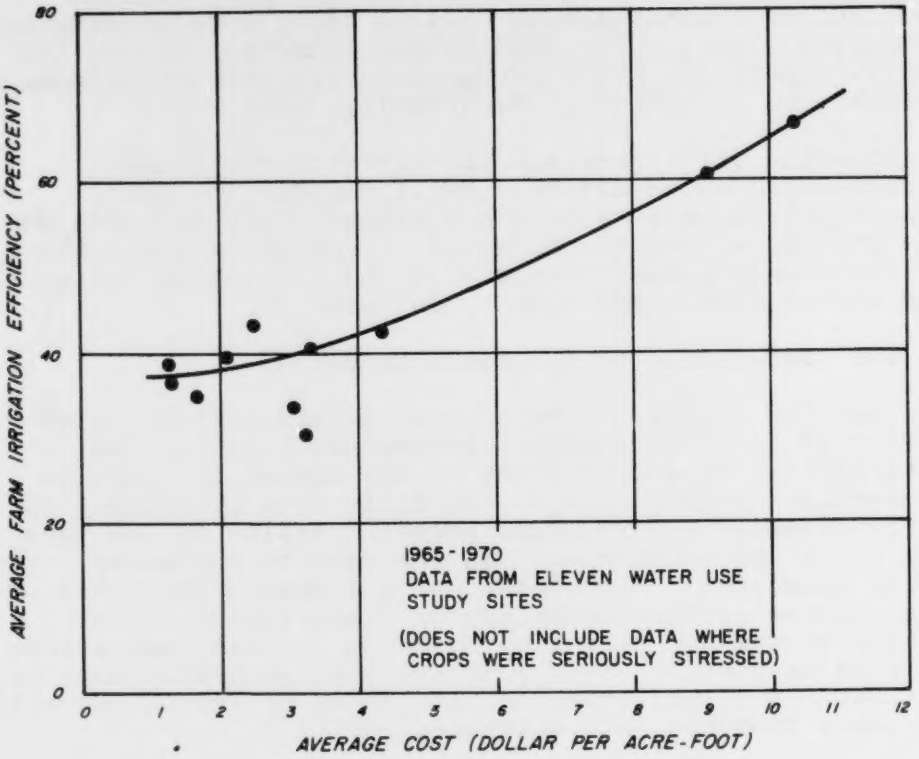

FIG. 5-4. DATA SHOWING RELATIONSHIP BETWEEN IRRIGATION EFFICIENCY AND WATER COST [A]

[A] USDI, 1973

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The first component of ISS involves visits by technicians trained in soil and water relationships. Such visits are likely to occur on a weekly basis. While on the farm the technician should check soil moisture at several places and depths. This may be done using traditional methods such as feel, augers, porus cups, and tensiometers. Samples should also be taken for gravemetric oven analysis. The soil should be analyzed for water holding capacity, wilting point and field capacity for gravemetric and suction analysis in the lab. New devices such as neutron probes will be calibrated to laboratory soil moisture analysis as they become refined and costs are reduced. When new soil water measuring devices become more developed, it is expected that they will replace many of the traditional devices.

The technician should also test infiltration rates at several places in the field. Infiltration rates vary through the season and this should be studied as well. The technician should give advice on irrigation practice to the farmer. This advice would be based upon observation of advance and recession characteristics in surface irrigation as well as the soil moisture status, holding capacity and infiltration rate. The technician should advise the farmer of the necessary depth of application and the size of the furrow stream and time of set necessary to achieve this application. The technician should also be prepared to aid the farmer in considering and seeking engineering help for system improvements.

Perhaps the most important job of the technician is to communicate. All of the data collected on the farm and from the computer simulation is no good unless it can be communicated to the farmer who is the final judge of when and how to irrigate. The farmer must gain confidence in the service in order to continue as a subscriber.

Initially, technician visits to the farm must be fairly frequent, perhaps greater than once per week. As time progresses, visits can be fewer, although weekly visits are advisable.

Flow measurement is the next element involved in irrigation management. Without flow measurement there can be no irrigation management. With sprinkler irrigation, it is desirable to measure diversions in order to determine the net water application rate.

A number of methods are presently available for determining the timing of irrigation applications. The aspect of irrigation timing represents an extremely vital service provided by an irrigation scheduling program. The sophistication of the effort expended in defining water scheduling varies from:

- Mere publishing of pan-evapotranspiration data;
- Calculating evapotranspiration for various crops in a general area using wind-run, pan-evaporation, temperature, and solar radiation;
- Field by field calculation of evapotranspiration which considers not only climatological data and type of crop, but also planting date;
- Intensive periodic measurement of field soil moisture as a means of determining crop evapotranspiration.

When evapotranspiration is calculated, computers are used in all but the most primative of services. The efficiency of the computer in processing data allows evapotranspiration to be computed through use of relatively sophisticated analytical procedures, such as that represented by the Penman method.

When an irrigation scheduling program includes on-farm field service, accuracy of water application timing is often improved. Field service involves:

- Assessment of available soil moisture through neutron probe testing, speedy moisture meter testing, or soil sampling and oven testing;

- Prediction of future crop use based on computed evapotranspiration or based on the periodic change in soil moisture;
- Prediction of next irrigation by establishing the date when available soil moisture will be on the order of 50 percent.

A graphical analytical procedure based on neutron probe soil moisture determination has been proven to be an effective means of guiding irrigation scheduling activities. To schedule an irrigation correctly, two criteria are needed:

- Determining the amount of water available to a crop;
- Determining the water use rate by the particular crop.

Timing of a required irrigation is established by means of relating available water to the water use rate. Assessing available water has been simplified to a great extent through use of the neutron probe. To correctly schedule an irrigation by using the neutron probe requires identification of the refill point (the point at which irrigation should occur) and periodic moisture measurements by the neutron probe. No other information is needed. Periodic measurement of soil moisture will describe both the ambient soil moisture and the rate of water use by a particular crop (Gear, et al., 1977).

A simple graphical analysis can then be used to accurately forecast the date of the next irrigation. This is done by plotting soil water content versus time on a graph, with the refill point indicated. Potential errors created by interim weather change are quickly and accurately accounted for by plotting a subsequent neutron probe measurement (ibid).

ISS is catching on and is expected to grow considerably. Jensen (1975) conducted a survey of firms offering such services in 1974. He surveyed only services which offered at least one visit per week to the farm and which used computer simulation. In 1974, field by field ISS was provided to 7,900 fields and approximately 3 million ha (7,385,000 acres) by all groups.

In 1974, at least ten commercial firms offered services in eight states on approximately 3 million ha (7,250,000 acres) of land. Of the commercial firms, most offered nutrient advice and about half offered pesticide and irrigation system improvement advice as well as scheduling. Nearly all of these services based scheduling on climatic data and deemphasized in-field soil moisture measurements as input to the computer program. Soil moisture was monitored mostly by probe and feel methods, practices which were subsequently used as a backup to the computer data. The reliance on these methods emphasizes the importance of development of neutron probes and other quick moisture measuring techniques.

In addition to the commercial ISS, two state agencies and the Bureau of Reclamation offered services. These agencies accounted for 54,000 ha (133,000 acres). Operation of the free agencies was similar to the commercial firms, although less services were offered.

Irrigation scheduling by itself is not a panacea for controlling pollution from return flows. Combined with improved on-farm practices it may be quite effective, however. Loading of nitrates is also reduced considerably since the amount of leachate is reduced. While actual improvements in on-farm practices cannot be expected to equal demonstration projects, significant reductions could still be achieved. With enough incentive, on-farm practice could be greatly improved, but unfortunately little incentive exists.

Minimum leaching is a concept of leaching only enough water from the root zone such that crop yields are not reduced. At least some crops are insensitive to the leaching fraction as long as a minimum leaching fraction is achieved (Van Schilfgaarde 1974).

While adoption of minimum leaching fractions could greatly reduce salt loading in drainage, it is a long way off. Irrigation systems don't distribute water evenly enough, and farmers are unlikely to cooperate.

The concept of minimum leaching is valid and has been proven (Van Schilfgaarde 1974; King, Hanks 1973). Using soil salinity sensors as an additional input to irrigation scheduling programs combined with sprinkler or trickle irrigation is a workable method of reducing salinity loading. While computer scheduling is here today, adopting minimum leaching is in the distant future.

The impact of crop yields has been demonstrated by the Bureau of Reclamation. For areas where irrigation scheduling was used, crop yields were increased by around 15 percent.

Since drainage water eventually finds its way back to the stream, flows downstream would not be changed. Farm efficiency can be expected to increase 10 percent (Jensen 1975), however. This water would be available to other non-consumptive users through the section. Increased quality through less leaching means downstream users would not have as much salt to leach. Efficiency improvements represent a benefit although they may not be quantifiable in terms of total water consumptively used in a basin.

The success of existing scheduling services indicate that few severe problems exist. Further development is needed on crop-use curves, and rapid soil moisture measuring techniques. In addition, there is a shortage of trained or experienced employees as with anything new (Jensen 1975). In many cases, irrigation systems need improvement and flow measuring devices in order to realize the benefits of ISS.

There are no direct institutional conflicts toward the implementation of ISS. The resistance to change represents a problem, but is being overcome by the evidence of the benefits of ISS.

Many areas of the country could benefit from such services where none exist. The development of services in these areas may be slow in coming without government incentive. Many services offered to farmers now are supported by taxes. Irrigation scheduling has proven successful as a commercial enterprise and has many benefits as such.

5.5 EXCESS WATER REMOVAL SYSTEMS

Systems which carry away tailwater and excess leachate represent the connection between the return flow from a particular field and an actual water quality impact. Alternatives in water removal systems can have effects upon water quality.

5.5.1 Tailwater Systems

Tailwater returns are generally carried away by a ditch. These returns are often directly re-used for irrigation of lower fields or farms, and in this case do not impact water quality. Where tailwater return flows impact water quality, alterations to the return flow system may be able to reduce pollution. Tailwater return systems, mini-basins, sedimentation ponds, grassed wasteways, and buffer strips are examples of such alterations to the return flow system.

Tailwater Recovery

Tailwater recovery involves catching tailwater from surface irrigation and pumping it back for use on the same farm, or using tailwater on a down slope field. With tailwater recovery, surface runoff and associated pollutants (phosphorous, sediment, and the majority of pesticides) can be reduced to zero. Tailwater return systems may either return water as it arrives at the bottom of the field or use a storage facility to hold water for later use. Tailwater systems have paid for themselves in several areas.

Phosphorous and sediment are recognized as being transported by surface runoff (tailwater). In addition, surface runoff is a major transport mechanism for pesticides. Tailwater reuse is not considered to be effective in reducing loadings of nitrogen or salts.

Reduction in pesticide loading would be related to the transport mode of the particular pesticide.

Sedimentation Basins

Sedimentation basins may be used to settle out some of the sediment. Such basins may be constructed by damming up natural stream beds, gullies or draws, or by excavation. The sediment trapped can be utilized in turning gullies into usable land or redistributed. Sediment ponds must be considered a short term solution, since they become filled up (Robbins and Carter 1975).

Sediment ponds are only effective in trapping sands and silts. While some clay will settle in a pond with sufficiently low flow-through velocities, the proportion of the total clay removed is small for most pond designs. Most sediment attached phosphorous and pesticides are attached to the clay particles. Thus, while some removal of phosphorous and pesticides may be expected, the proportion will be smaller than the percent of sediment removed by weight. However, phosphorous output in an Idaho study was significantly reduced (Bondurant et al 1975).

Removal of clay particles requires techniques other than sediment ponds such as chemical flocculation or vegetated strips (Carter 1976). If ponds receive a high loading and are to be of continued service, they must be cleaned on a seasonal basis. A dragline or other equipment may be required for the cleaning (ibid).

The ideal pond is triangular in shape with a narrow entry and a wide exit to allow a continually decreasing forward flow velocity. Forward velocity, particle size and length considerations are displayed on Figure 5-5. These considerations are based on Stokes law and are not applicable to clay particles (Bondurant, et al 1975). Pond design should consider volumes of sediment expected and the size breakdown of this sediment. The usefulness of the pond is governed by its ability to remove the particles causing the pollution problem.

In the Twin Falls, Idaho area, considerable work has been done with sedimentation basins. Sediment has been a significant water quality impairment to the Snake River and ponds have been used effectively in reducing the load. These ponds are considered to be a short-term solution (Robbins and Carter 1975.) The more sediment-laden the water, the more effective the pond. Sedimentation basins are not effective in removing disaggregated clay particles. While design and construction may be fairly simple, ponds must either be cleaned out if sediment loads are significant or allowed to fill in. Ponds which are allowed to fill in eventually lose their effectiveness and other control measures must be taken. Cleanout represents a continuous maintenance requirement and requires heavy equipment which the farmer may not have.

Mini-Basins

Mini-basins are small shallow ponds constructed on the lower end of a field by putting in a low berm along the bank of the drain ditch. Other berms are constructed perpendicular to the drain ditch, so that each basin retains the tailwater flow of just a few furrows. The berm along the drain ditch also serves as a spillway when necessary, so it should be seeded with grass to minimize erosion into the ditch. Mini-basins typically retain 90 to 95% of the sediment. (Fitzsimmons et al, 1977; Lindeborg et al, 1977).

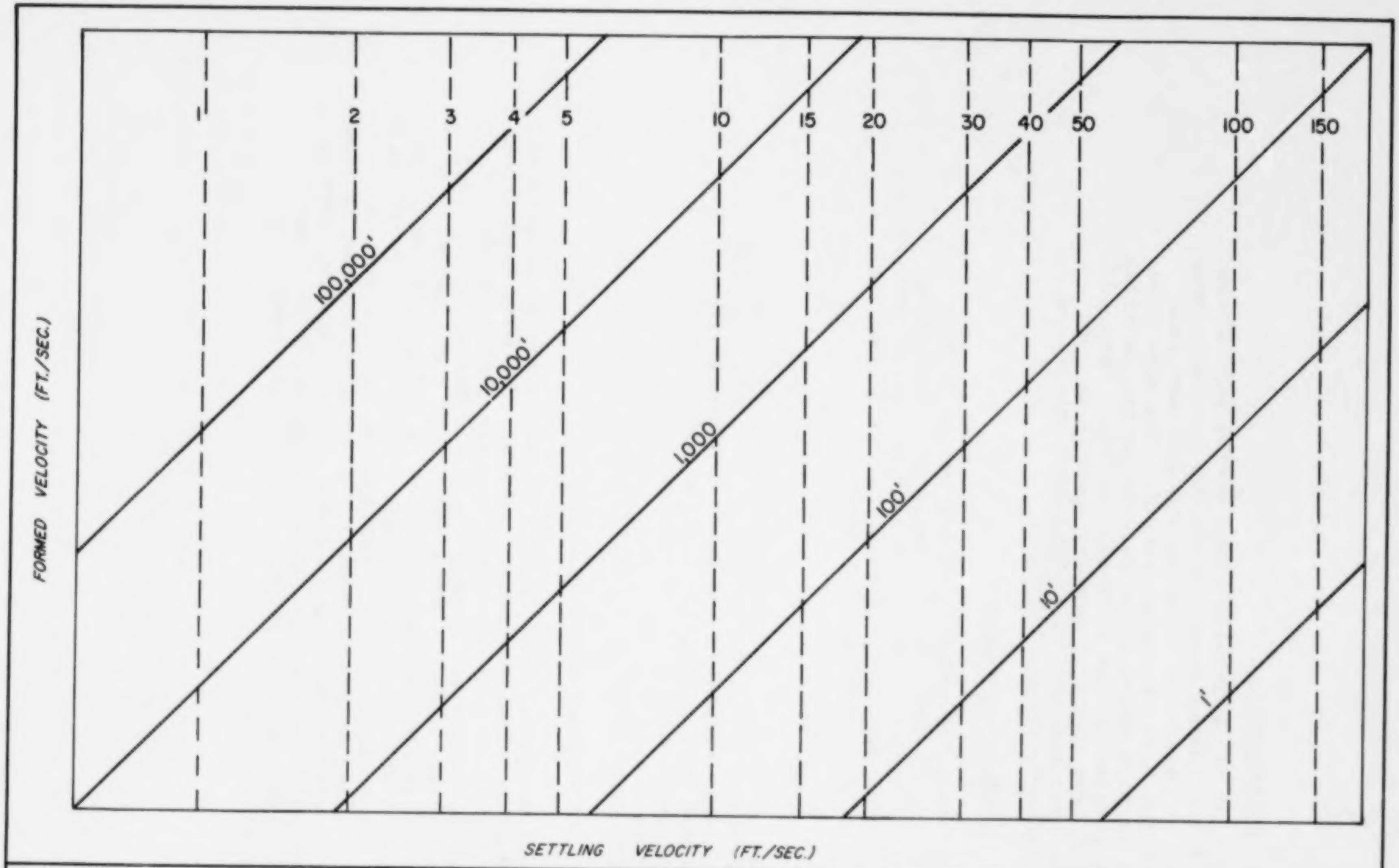

FIG. 5-5. POND LENGTH REQUIRED FOR QUARTZ PARTICLES TO SETTLE ONE FOOT AT VARIOUS FORWARD VELOCITIES, USING STOKES' LAW [A]

[A] Bondurant, 1975.

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Buffer Strips

Strips of close growing crops at the end of the field--including grass, grain, or hay--have been found effective in reducing the sediment load resulting from tailwater runoff. The slow movement through these crops results in the settling of a portion of the suspended solids. Results varied from about 40 percent removal to over 90 percent removal, depending upon conditions. (Fitzsimmons et al, 1977).

Grassed Waterways

Vegetated return flow channels can be highly effective in settling out sediment. Depending upon the type of vegetation, the vegetated channel may potentially serve a dual purpose as pasture, hay ground or wildlife habitat.

5.5.2 Drainage

While variations of subsurface drainage systems have been studied for pollution control, they are not widely adaptable and won't be extensively reviewed here. Articles dealing with using submerged drains for denitrification or using shallow drains to remove only the shallow, less saline groundwater are listed in the Bibliography.

5.6 SOIL CONSERVATION PRACTICES

Traditional soil conservation measures may be effectively used as a pollution control option. Yet many traditional techniques successful under rainfall conditions do not apply to furrow irrigation (Mech and Smith 1967) . Such measures are aimed at reducing runoff and erosion. In arid irrigated regions, rainfall of sufficient magnitude to cause erosion is infrequent (Carter 1976). Furthermore, irrigation by good sprinkler systems will produce no runoff, and border systems are generally confined to flat ground with close growing crops offering minimal erosion potential. Furrow irrigation on the other hand has significant erosion potential and is the predominate form of irrigation.

Soil conservation measures may conflict with irrigation practice and pollution control in two ways: 1) irrigated agriculture may require high value crops year after year in order to be economically favorable; 2) minimum tillage measures may not be favorable from a production standpoint and while reducing sediment loading, may increase loadings of nitrogen and phosphorous when chemical fertilizers are added to the surface (Romkens 1973). While conflicts may rule out some types of soil conservation measures, others may prove to be effective.

Erosion control methods may either reduce runoff or reduce erosion. Most methods are effective at both. Carter (1976) lists ten general methods including:

1) Eliminate or reduce irrigation return flows when conditions permit by using irrigation methods with little or no runoff (such as sprinkler or truckle irrigation, discussed elsewhere in this report);

2) Put furrows on the contour and decreasing slope towards the end of the furrow;

3) Control furrow stream size and make proper stream adjustments adequate measurement, and controls as necessary;

4) Shorten length of run;

5) Control the irrigation duration to reduce the number of irrigations per year. Alternate furrow irrigation may also reduce contact;

6) Cultivate only when necessary avoiding excessive soil loosening which increases erosion and soil loss;

7) Control tailwater by assuring that it flows slowly enough that sediment settles before the water leaves the field. Filtering through grass strips removes sediments;

8) Utilize sedimentation basins to remove sediment from return flows.

Most of these options are discussed elsewhere in this report. Others are self evident. Quantitive prediction of results is only possible for no runoff options. Other options cannot be quantified as to effectiveness without individual site analysis.

Cultivating only when necessary is a traditional soil conservation method. Soil losses may be around 10 times greater after the first irrigation after cultivation than during succeeding irrigations (Mech and Smith 1967). While soil losses may be less under minimum cultivation, losses of surface applied fertilizer may be higher (Romkens 1973). Problems might be encountered in using conservation tillage, since salt accumulations at the furrow peak may have to be plowed under.

Rainfall area soil conservation practice includes no till planting in prior crop resideues, conservation tillage, sod based rotations, meadowless rotations, winter cover crops, improved soil fertility, timing of field operations, plow-plant systems, contouring, graded rows, contour strip cropping, terraces, grassed outlets, ridge planting, contour listing, change of land use and others (Stewart et al, 1975). While it is good to know these methods since they may prove useful, they are not generally applicable to irrigated agriculture.

5.7 FERTILIZER RESOURCE MANAGEMENT

Management of fertilizer applications has significant potential for reducing nutrient pollution. Fertilizer management involves using optimum application rates, timing and type of fertilizer, as well as proper incorporation into soil. Water management must also be considered as a fertilizer management tool, as must erosion control. Best management in fertilizer use creates benefits for both the farmer and the environment.

The application of more fertilizer than can be effectively used by the crop is a situation of waste. Determining nitrogen fertilizer requirements is difficult. No rapid soil test is available to provide an adequate estimate of soil nitrogen available to crop during a season. Field tests combined with local experience appears to be the best tool currently available. Timing fertilizer applications and water applications is perhaps the most important aspect. If spring leaching for salts is practiced, nitrogen should be applied afterwards.

Rotating crops from high nitrogen users (such as corn) to plants not requiring chemical fertilizer, especially deep rooted ones such as alfalfa, can be effective in the utilization of nitrates in the lower portions of the soil (Stewart 1975). Unfortunately, economics may dictate a mono-culture.

Minimizing leaching while maintaining a safe salinity level in the soil is the most significant way to control fertilization, especially if coordinated with proper fertilizer application rates and well planned timing of fertilizer use.

5.8 EFFECTIVENESS AND COST OF POLLUTION CONTROL

The cost of altering practices for pollution control should not be considered in terms of cost of the practice along, but also should take into consideration the change in labor requirements, crop yield, and other operation and maintenance costs which result. Costs vary not only with time, but also with locale.

Effectiveness for pollution control options is also very highly dependent upon the specific application involved. Soils, crops, and other localized conditions make a difference.

Increased irrigation efficiency (reduced leachate and runoff) is the only universally effective method of irrigated agriculture pollution control. Other methods of pollution control tend to deal with specific pollutants.

In this section, pollutant control options will be discussed as they relate to specific pollutants. This information is summarized in Table 5-4. The effectiveness of control measures presented here relates only to the results which can be achieved in a particular field or application site. Effectiveness on the basin-wide level is complicated by re-use of return flows, changes occuring during transport, etc.

5.8.1 Salinity

The effectiveness of salinity control options is dependent upon local conditions. In most areas, salinity levels are due to consumptive use alone. In a few areas, however, weathering of saline rocks and soils has been shown to represent a significant salt load. In these areas, potentials for reducing salt load are much greater.

Where consumptive use is the only significant cause of increased salinity, the potential for reduced salinity loading is very small. Strategies aimed at reducing salinity concentrations must either reduce non-cropland consumptive use, reduce cropland consumptive use, or increase salt storage in and below the root zone. These strategies, with the exception of salt storage below the root zone, are aimed more at reducing concentration by making more water available. Such strategies may then be evaluated in terms of water conservation potential.

TABLE 5-4 ESTIMATED REDUCTION IN POLLUTANT LOADING FOR VARIOUS CONTROL OPTIONS AS COMPARED TO FURROW IRRIGATION

	Pollutants				
Control Option	Reduction In Deep Seepage Water Loss	Nitrates	Sediment	Phosphorous	Pesticides (1)
Irrigation Scheduling	5-10%	5-10%	0- 5%	0- 5%	0- 5%
Lateral Lining & Pipeline	5-20%	0	0-10%	0	0
Canal Lining	5-20%	0	0-10%	0	0
Improve Surface Systems (2)	5-30%	5-30%	10-60%	10-60%	10-60%
Sprinklers	20-50%	30-50%	90-100%	90-100%	90-100%
Dead Level Irrigation	20-50%	20-50%	100%	100%	100%
Land Leveling	0-25%	0-25%	0-10%	0-10%	0-10%
Drainage	5-20%	0-10%	0	0	0
Water Measure Device	0- 5%	0- 5%	0- 5%	0- 5%	0- 5%
Mini-Basins	0	0	85-95%	85-95%	85-95%
Sediment Ponds	0	0	40-90%	40-90%	40-90%
T.W. Pumpback	0	0	50-100%	50-100%	50-100%
Buffer/Filter Strip	0	0	30-60%	30-60%	30-60%
Grassed Waterways	0	0	5-40%	5-40%	5-40%
Slow Release Nitrogen	0	10-30%	0	0	0

(1) Pesticides traveling with soil only.

(2) Improve distribution system, proper length of run, cut back operation.

In this context, water conservation potential means reduction in consumptive use only. As an example, assume a canal to an irrigation project lost 25 percent of its water to seepage and phreatophyte use. It has been determined through study of aerial photographs and the plants involved that phreatophytes used 5 percent of the 25 percent loss. The remaining 95 percent of seepage loss went to the groundwater without quality degradation. This groundwater eventually went back to the stream without quality degradation. Canal lining could reduce this non-beneficial consumptive use along the canal by 90 percent. The resulting water conservation effort would save 0.25 x 0.05 x 0.90 = about 1 percent of the total project water. This 1 percent of the water would then be available for dilution. Total salt loading would be unchanged by such practice, however.

Reduction of salt loading through reduced leaching fractions (increased irrigation efficiency) must be considered in regard to a specific soil. Where the reduction in salt loading is dependent upon storage in the soil below the root zone, it is doubtful as to whether irrigation practices over a large region can be tailored to the necessary precision. Table 5-4 gives estimated reductions in leaching fractions for several BMP's; reduction in salt loading is not so readily predicted.

Where saline soils or rocks result in salt pickup, it is expected that potential improvements will result in a more significant reduction in salt load. From this standpoint, pollution reduction potential must be considered in terms of the quality change which would occur to waters lost to the groundwater.

Since any potential quality change resulting from loss of water to deep seepage is highly localized, it is impossible to talk about the effectiveness of pollution control measures in the general sense. We must, rather, consider the reduction of water traveling a certain pathway. Quality changes this water would undergo should then be considered under local conditions. Table 5-5 presents typical volumes of water lost to deep seepage under several systems.

TABLE 5-5. AVERAGE WATER LOSSES TO DEEP SEEPAGE FOR IRRIGATION SYSTEMS

System	Percent of Water Delivered To This System Lost To Deep Seepage	
Conveyance Systems	Range	Average
Canals, Laterals or Head Ditches, Unimproved	3-40	20
Concrete Lined or Pipeline	0-10	5
Application Systems		
Furrow or Border Irrigation	5-50	30
Furrow or Border With Good Management, Irrigation Scheduling	5-40	20
Sprinkler Irrigation*	5-30	10-15
Dead Level Irrigation	5-30	10-15

* Evaporation losses may average 5 to 10%.

5.8.2 Nitrates

Nitrates are associated with leaching of irrigated fields. Control measures include better application efficiency (reduced leachate) and better fertilizer management. Better fertilizer management could probably result in a 10 to 20 percent reduction of nitrate concentrations in the leachate, although supportive data is lacking. Reduced deep seepage losses (improved irrigation efficiency) offer the real key to reduced loading. Nitrate leaching is especially problematic on sandy soils. Achieving efficient surface irrigation can also be quite problematic on these sandy soils. For these reasons, reduction in nitrate loading can be closely related to reductions in deep seepage losses. Without change in fertilizer practices, significant changes in nitrate concentration of percolating waters could not be expected.

5.8.3 Sediment

The effectiveness of sediment control measures is related to both the quantity of surface runoff and the quality of that surface runoff. Any reduction in quantity can be expected to reduce the tonnage of loss to at least an equal percentage. In fact, reductions in quantity typically result in significantly greater reductions in total loading, since runoff velocities are less. Several systems can totally eliminate the pollutants associated with it--sediment, phosphorous, and many pesticides. These systems are:

- Tailwater return
- Sprinkler irrigation
- Dead level irrigation

Fitzsimmons et al (1977) and Lindeborg et al (1977) present expected results and costs for sediment control systems. These are presented in Table 5-6.

TABLE 5-6. EXPECTED SEDIMENT LOSS REDUCTION FOR SELECTED CONTROL PRACTICES ON TYPICAL IRRIGATED FARMS IN THE MAGIC VALLEY AND BOISE VALLEY (1)

Control Practice	Percent of "Typical" Sediment Loss Retained On Farm
Flow cut-back	30
Grass or grain strip	50
Sediment pond	67
Mini-basin	90
Sprinklers	100

(1) Lindeborg et al 1977.

5.8.4 Other Pollutants Associated with Surface Runoff

Loading of phosphorous and pesticides associated with sediment or surface runoff can probably be assumed to be reduced at least as much as sediment loading by a given practice, although very little data is available at the current time.

5.8.5 Costs of Irrigated Agricultural Practices

Costs of agricultural practices vary from region to region as well as with time. Justification of costs should consider crop value, labor costs and others as well as fixed costs. Consultation with local irrigation system contractors, chemical dealers, and agricultural experts can be expected to produce accurate costs. Doanes Agricultural Service publishes machinery operations costs and other costs on an up-to-date basis for most regions.

Cost-effective analysis compares the equivalent annual cost of potential best management practices with their effectiveness in reducing pollutant load. Equivalent annual cost includes:

- Annualized capital cost
- Annual operation and maintenance costs
- Annual labor cost
- Annual cost or benefit of altered crop yields
- Annual cost or benefit of altered chemical use or tillage operations.

Equivalency of units is required for comparison purposes. Since the cost of most practices is dependent upon land area, dollars/acre/year or dollars/hectare/year provide a good comparison criteria. Assumptions may be required to develop equivalent units. Lindborg et al (1977) present an excellent economic analysis of sediment control practices.

Costs presented in the case study in Chapter 3.0 represent costs in northern Colorado in 1977. Efforts should be made to localize costs prior to conducting an analysis such as seen in Chapter 3.0.

6.0 WATER LAW

Since the passage of the Federal Water Pollution Control Act Amendments of 1972, all states are involved in water pollution abatement or elimination efforts. In addition, they are responsible for water resource allocation for the many uses made of this resource. In the western states where irrigated agriculture is a substantial and important part of the economy, water quality laws and water resource (or quantity) laws are having more impact than ever before. Potential solutions for irrigated agriculture water pollution problems are often times just as dependent upon institutional and legal constraints, as technical and financial capabilities.

6.1 WATER QUALITY LAW

Prior to the Federal Water Quality Control Act of 1965, individual state water quality laws varied significantly in purpose and scope and had little uniformity. Since that time, and especially after passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) the states have been following uniform Federal programs, with minor variations from state to state. The objectives of PL 92-500 were to provide Federal/State programs to prevent, reduce, and ultimately eliminate water pollution. It seeks to achieve fishable, swimmable waters, wherever attainable by 1983.

Radosevich (1977) has separated the Act into five basic components:

1. Water Quality Policy
2. Criteria for Pollution Control
   a. Classification of Waters
   b. Water Quality Standards
   c. Effluent Discharge Standards
3. Control Activities
   a. Permit System
   b. Construction Grants and Programs
   c. Public Participation in Planning and Setting Standards
4. Sanctions and Enforcement Measures
5. Administrative Structure

The Act identified two sources of pollution: point and nonpoint. Point sources are end-of-pipe discharges such as those from municipal sewage treatment plants, industries, and some concentrated animal feeding operations. Such sources are controlled through a system of individual permits which prescribe types and amounts of pollutants allowable in the discharge and include implementation plans and provisions for self-monitoring.

Nonpoint pollution sources pose a more difficult problem. They are caused by precipitation runoff and/or seepage which ultimately reaches waterways. Examples include: surface runoff from urban areas, farms, or construction areas; mine drainages, waste disposal areas; and septic tanks.

Irrigation return flows of all types are considered to be nonpoint sources according to 1977 amendments to PL 92-500. Section 208 of the 1972 Act provides for areawide waste treatment management plans which are intended to address the nonpoint source problem and establish programs for solution.

6.2 WATER ALLOCATION LAW

State water allocation laws began evolving during the settlement of the eastern states and are still changing today. With no guidelines to follow, eastern states adopted England's common law riparian doctrine as a policy for controlling waters. As settlement and development moved westward, local customs, state laws, and individual court cases determined water rights. From this, a doctrine of prior appropriation evolved and was adopted by nearly every western state. Many states' water law is a combination of the two. In fact, each state has developed its own unique system of both surface water and groundwater laws. It is commonly held that water rising within or occurring below a state's boundaries are under its jurisdiction, unless subject to powers reserved for the Federal Government. Figure 6-1 describes surface water laws systems in the western states.

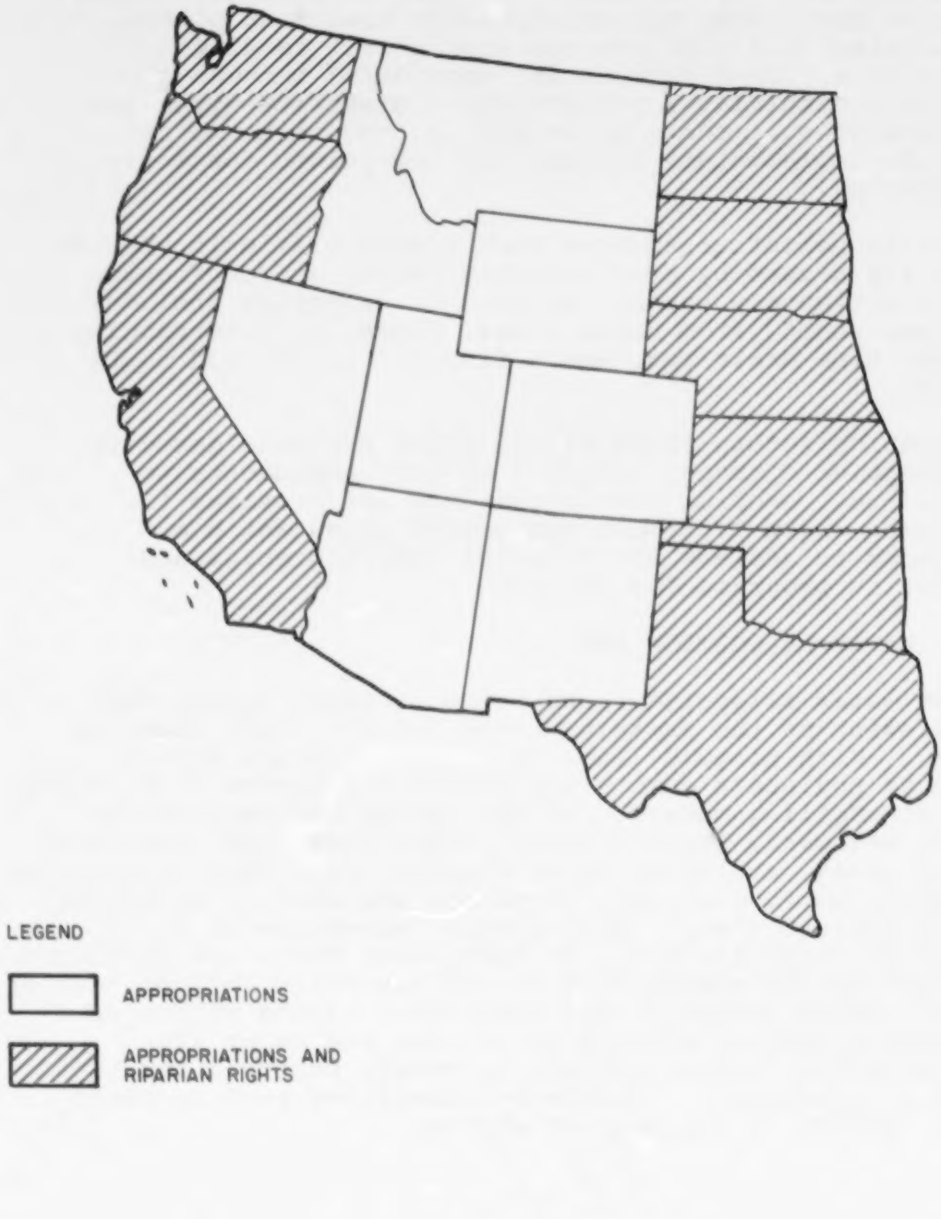
LEGEND
APPROPRIATIONS
APPROPRIATIONS AND RIPARIAN RIGHTS

FIG. 6-1. SURFACE WATER LAW SYSTEMS IN THE WESTERN STATES

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6.2.1 Riparian Doctrine

This system follows the natural flow theory which states that a landowner adjacent to a river or body of water is entitled to use that water. The second concept is that of reasonable use. Riparian landowners can divert a reasonable amount of water with respect to other riparians on the stream for beneficial use. Hence, he is a correlative co-user with all other riparians on the water source and priority of use does not establish priority of right in times of decreased flows. The right to use water is dependent on the extent of development, not a fixed quantity of water. Natural wants or domestic uses hold preference of use over other uses. Reasonableness of use determines preference between other uses: agriculture, industrial, and recreational.

An important characteristic of a riparian water right is that the right will continue as long as the land and water source remain contiguous. Abandonment of the right is nonexistent through nonuse or misuse; however, misuse may result in a restriction of use and/or judgement for damages.

Recent changes include establishment of:

1. A permit system (limitation on duration) for allocation
2. Administrative machinery to assess supplies and requirements
3. Forfeiture (not to be confused with abandonment) for nonuse
4. Minimum flow requirements
5. Greater flexibility and certainty in acquiring right.

Again, each state totally or partially following the riparian doctrine is unique in its system of water allocation and has adopted some or all of these changes in varying degrees.

6.2.2 Doctrine of Prior Appropriation

This system of water resource appropriation applies the same principle as used in staking mining claims, namely "first in time, first in right." Unlike the riparian doctrine, a right to use water does not automatically exist by virtue of location. A diversion from a natural body of water is first needed. Second, the water must be applied to a beneficial use. After the diversion and beneficial use was completed, a "water right" was created. Then each right acquired a priority date. The priority of right and not equality of right is the basis for distributing water.

This water right is a real property right and is commonly described as an usufructuary right - a right to use the resource. In addition, there is no absolute ownership prior to diversion. After diversion and prior to escaping the right holder's control, it is considered personal property. Summarizing, this appropriated water right:

1. Exists to a certain source
2. Is divertable (fixed and stated quantity)
3. Has a point of diversion to maintain conditions
4. Has a specified use
5. Identifies place of use
6. Implies annual time of use
7. Assures holder of an implied protection of quality.

There are several key elements contained in the doctrine of prior appropriation which will be dealt with in relation to irrigation return flow later in this chapter. The discussion that follows attempts to summarize these key elements. The actual process of water appropriation is considered complete after three steps. First, an application is filed with the proper state authority. The appropriation will then be granted if unappropriated water is available, if it will be put to beneficial use, and if the public interest will not be adversely affected. Finally, diversion and beneficial use must take place before the applicant receives a right to the water.

The concept of "beneficial use" for an irrigator desc-ibes that amount of water necessary to irrigate his land in a beneficial manner. Closely associated to beneficial use is "duty of water." Duty of water, often statutory in nature, refers to the quantity of water in terms of reasonableness. It is that measure of water which by careful management and use, without wasteage, is reasonably required to be applied to any given tract of land to raise ordinary crops (Radosevich 1977). Waste is corollary to beneficial use, i.e., runoff is not considered waste, providing beneficial use criteria is met. The farmer need not apply latest technology nor limit return flow to zero. The test is reasonableness, not mathematical exactness. Local customes or methods can serve as a guide.

Preferences and priority to use are often confused. The date of right is the distinguishing factor for priority to use. Preference to use refers to type of use given preference by laws - agricultural, domestic, industrial, recreational, etc.

There are four ways through which loss of water rights can occur:

1. Abandonment - failure to use the entire appropriated right for a statutory period of time with intention of abandonment.
2. Forfeiture - nonuse of water for statutory term with intent being irrelevant.
3. Adverse possession - one person uses another persons water who does nothing about it.
4. Condemnation - similar to police power by preferred user or public entity.

Another element in the doctrine of prior appropriation concerns the transfer of water rights. In most states a water right is appurtenant to the land on which it is used thereby restricting the transfer of rights. There are certain restrictions in transfers of rights (Celnicker 1974), such as:

1. No other appropriation can be hurt.
2. While a change may be approved, conditions necessary to prevent injury to others must be included.
3. In some states transfer procedures are provided by law.
4. Some state statutes specifically declare that water rights cannot be detached from the lands, place or purpose for which they are acquired, only with certain exceptions.
5. Other states require that it become impractical to beneficially or economically use water on appurtenant land before transferring.
6. Inadequate measurement and poor records add to costs and uncertainty.

These restrictions in transfers become important in the question of efficient use of water and loss of water rights.

6.2.3 Ground Water Control Systems

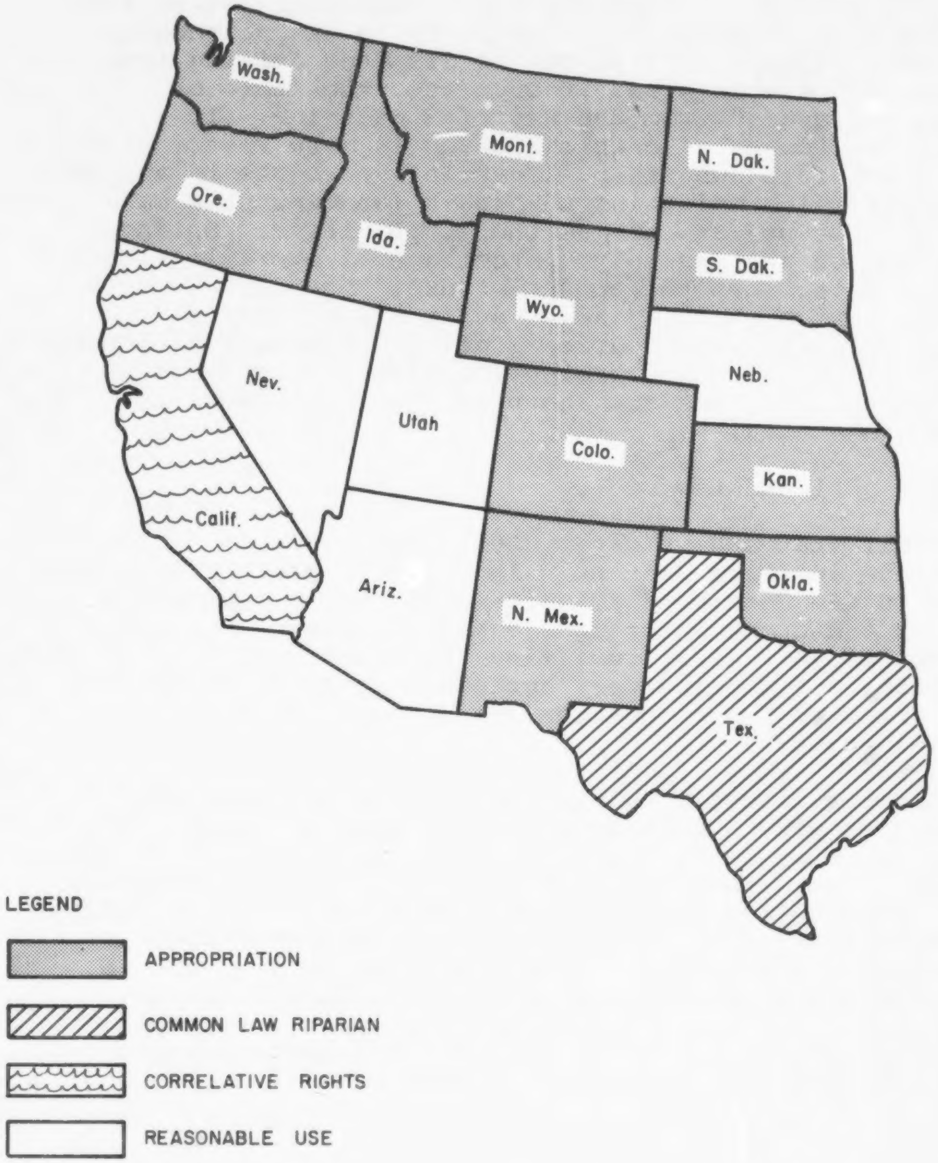
Radosevich (1977) has categorized groundwater allocation doctrines into four types commonly found in the western states. Even though groundwater has been a source of water for many uses for many years, some states have within the past 10 years adopted regulations to control this resource. This body of law and system of allocation has developed for each state through case law, customs, and established practices.

The first doctrine is that of absolute ownership. Simply stated, a landowner may withdraw any water from beneath his land without liability to his neighbors. A second system evolved out of disputes arising from absolute ownership and incorporated the "rule of reasonable use" from the Riparian Doctrine. It is referred to as reasonable use and is more restrictive than absolute ownership. Correlative rights is a third concept which maintains that each landowner can make reasonable use as long as the supply lasts. During periods of short supply, percentage of overlying land owned determines the amount of use. The last kind is prior appropriation. As in surface water prior appropriation, the source is allowed maximum development with recognition and protection given prior users. These four systems are shown in Figure 6-2 for the western states.

6.2.4 Related Law

Several states have water users conjunctively using surface and groundwaters. In order to protect interests and insure continued resource development, augmentation plans and groundwater management districts have been established. Also, realizing the interconnection between surface and groundwater, surface rights can be retired if affected by groundwater resource allocation and development.

While not directly related to allocation laws, two concepts govern drainages on agricultural lands. The common enemy rules says that a landowner can construct dikes, etc., to protect his land from upland drainages or uncontrolled runoff. Conversely, the rule of natural drainage gives an advantage to the landowner above or at higher elevations. Drainage from his land should be allowed to follow the natural drainage patterns. The most reasonable interpretation of both concepts states that there can be reasonable interference by either party to protect his property.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Calif.
Okla.
Ariz.
N. Mex.
Tex.
LEGEND
APPROPRIATION
COMMON LAW RIPARIAN
CORRELATIVE RIGHTS
REASONABLE USE

FIG. 6-2. GROUND WATER LAW SYSTEMS IN THE WESTERN STATES

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TABLE 6-1 CHARACTERISTICS OF WATER RIGHTS IN WESTERN STATES (Radosevich, 1977)

	Evidence of Water Right	Date of Priority	Preference of Use	Allocation Criteria (Duty)	Drainage Rules	Appurtency	Forfeiture of Rights by Nonuse
Arizona	Permit	A	1-2-3-4-5	BU	CE & CL	Strict	5 Years
California	Permit	A	1-2	B & RU	RD	Unlimited	3 Years
Colorado	Decree (SW) Permit (GW)	First Step A	1-2 over 5	BU	CL	None	10 Years is evidence of abandonment
Idaho	License	A	1-2	1 cfs/A	CL	Unlimited	5 Years
Kansas	Permit	A	1-2-5-6-3	1-2A-ft. 1A	CL		3 Years
Montana	Permit	A	None	1 Miners inch/A	CE		10 Years is evidence of abandonment
Nebraska	Permit	A	1-2 over 5	1 cfs/70A 3 A-ft/A	CE		3 Years
Nevada	Permit	A	None	Conditions & Needs	CL		5 Years
New Mexico	Permit	A	None	BU & Good Agriculture Practice	CL		4 Years + 1 Year after notice
North Dakota	Permit	U	1-2-5-6	1 cfs/80A	RD		3 Years
Oklahoma	Permit	A	None	BU	RD	Strict	7 Years
Oregon	Permit	A	1-2-4	BU	CL	Strict	5 Years
South Dakota	License	A	1	1 cfs/70A 3 A-ft/A	CL		3 Years
Texas	Permit	U	1-5-2-4-3-7-6	BU	CL		10 Years
Utah	Permit	A	1-2	Nature of Use	CE		5 Years
Washington	Permit	U	None	Reasonably Necessary	CE		5 Years
Wyoming	Permit	A	1-5	1 cfs/70A	Undecided	Strict	5 Years

A - Date of Application
U - Date of Beneficial Use

CE - Common Energy
CL - Civil Law
RD - Reasonable Discharge

6.3 EFFECTS ON BEST MANAGEMENT PRACTICES

Both water quality laws and water quantity laws are used in determining optimum management practices for a particular area to control water pollution from irrigated agriculture, specifically irrigation return flows. Each state is unique in its system of water pollution control and water rights allocation. There are numerous issues involving interpretation of case and statute law which should be analyzed on a state-by-state basis before implementing best management practices.

6.3.1 Water Quality Law Issues

The goal of the Federal Water Pollution Control Act is to have fishable, swimmable waters where attainable by 1983. Presumably, if all point and nonpoint source pollution were controlled based on effluent standards and water quality standards, this goal would be met. However, many rivers in the arid weatern states are used entirely for irrigation making the "fishable, swimmable" criteria unnecessarily restrictive. Even if that quality level could be attained, the quantity of water remaining in a river after diversions during irrigation seasons is sometimes too low to propagate aquatic life or recreation. The phrase "where attainable" has to be emphasized in the West.

A second question that many states have had to address concerns the terms "nation's water" and "navigable waters". Some states have included irrigation waters in the definition of navigable waters, thereby applying stream classifications and water quality standards to irrigation waters. While it is reasonable to require that return flows not degrade receiving waters, best management practices should be tailored to the level of water quality necessary to maintain an existing or recommended classification. Here again, case-by-case flexibility may reduce total pollution control costs.

6.3.2 Water Quantity Law Issues

These water laws have evolved to regulate the use of a limited resource in the western states. Although there exist only two basic surface water law doctrines and four groundwater law doctrines, each state has developed its own allocation system using different combinations of existing law. Also, case law in each state is unique, causing still more diversity. The technology involved with various best management practices is available, but not necessarily implementable in every state because of water rights laws restrictions and limitations.

Best Management Practices implies that the predominant pollution control strategy lies with management of the irrigation practice itself as opposed to collecting wastewater, applying treatment technology, and returning it to the stream. Any control option which allows an irrigator to divert his entire appropriated water right each year, to use that water beneficially and economically, and to discharge the return flow back into the stream in such quality and quantity as required by law, would not appear to pose any problem. The conflict begins when a management practice consumptively uses water belonging to a downstream user or endangers the irrigator's continued right to that water, by water management efficiency practices.

Many control options emphasize the efficient use of water, the theory being that high levels of agricultural production can be maintained using less water throughout the system, consequently reducing the amount of return flow. However, within the realm of the Prior Appropriation Doctrine, there are disincentives to efficient water use.

The potential for loss of water rights through abandonment and forfeiture encourages an irrigator to divert his total appropriated amount of water. A farmer will not place himself in a position of having forfeited a portion of his water right through nonuse during years of average or above average rainfall, knowing he will need his entire appropriation in the event of a dry year. More lenient water rights transfer provisions insuring a farmer access to his total appropriation when needed would encourage greater water use efficiency in wet years.

It is feasible that efficient on-farm use of water can result in additional quantities of water available for use. Differing court opinions have confused the answer to the question of whether an irrigator has the right to use that additional quantity of water. Although the general rule is that he can, the argument of appurtenancy remains. "Commendable practices do not in themselves create a legal right. Doctrine of beneficial use precludes application of water gained by conservation practices. Beneficial use is the measure and the limit to the use of water." (Salt River Valley Water Users Association vs. Kovacovich - Arizona) (Radosevich 1977). The case Reno vs. Richards (ibid) states the general rule "... if one, by his own efforts, adds to the supply of water in the stream, he is entitled to the water which he has developed even though an appropriator with more senior priority might be without water."

While there may be a fine line differentiating irrigation return flow and irrigation wastewater, certain case laws clearly distinguish the two in terms of recapture and reuse. Generally speaking, an individual irrigator can recapture wastewater in his own property and reuse it thereon. Also, a downstream user can appropriate wastewater, but he cannot be assured that the upstream user will continue to discharge. As a rule irrigation districts can recapture return flow before it leaves the district's boundaries; however, this rule is not normally extended to individuals. Reusing watewater may prevent injury to a downstream user in terms of water quality, but may cause injury because of decreased water quantity. Both irrigators are affected in this case.

In most states there are no explicit provisions regarding the protection of water quality in water allocation law. At best, the owner of the right has a vested right to the quality as well as the quantity which he has beneficially used. The quality to which an appropriator has right is that which is sufficient to "substantially fulfill the purpose for which his appropriation was made." Case law is very limited or non-existent with respect to private action based on pollution caused by return flow. Any damage, usually caused by many upstream users, must be substantial. Prior to new state water quality laws, any legal action must be brought by the downstream user.

APPENDIX A

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APPENDIX B

GLOSSARY

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GLOSSARY

Climate: The sum total of all atmospheric or meteorological influences, principally temperature, moisture, wind, pressure, and evaporation, which combine to characterize a region and give it individuality by influencing the nature of its land forms, soils, vegetation, and land use.

Consumptive use: The water used by plants in transpiration and growth, plus water vapor loss from adjacent soil or snow, or from intercepted precipitation in any specified time. Usually expressed as equivalent depth of free water per unit of time.

Denitrification: The biochemical reduction of nitrate or nitrate to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.

Erosion: (i) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (ii) Detachment and movement of soil or rock by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion:

- accelerated erosion: erosion much more rapid than normal, natural, geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals.
- gully erosion: the erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.
- natural erosion: wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Synonymous with geological erosion.
- normal erosion: the gradual erosion of land used by man which does not greatly exceed natural erosion.
- rill erosion: an erosion process in which numerous small channels of only several inches in depth are formed; occurs mainly on recently cultivated soils.
- sheet erosion: the removal of a fairly uniform layer of soil from the land surface by runoff water.
- splash erosion: the spattering of small soil particles caused by the impact of raindrops on very wet soils. The loosened and separated particles may or may not be subsequently removed by surface runoff.

Eutrophication: A means of aging of lakes whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment of waters with surface runoff containing nitrogen and phosphorus.

Evapotranspiration: The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

Fertilizer: Any organic or inorganic material of natural or synthetic origin which is added to a soil to supply certain elements essential to the growth of plants.

Fixation: The process or processes in a soil by which certain chemical elements essential for plant growth are converted from a soluble or exchangeable form to a much less soluble or to a nonexchangeable form; for example, phosphate "fixation." Contrast with nitrogen fixation.

Groundwater: Water that fills all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

Herbicide: A chemical substance used for killing plants, especially weeds.

Infiltration Rate: A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Irrigation Efficiency: The ratio of the water actually consumed by crops on an irrigated area to the amount of water diverted from the source onto the area.

Irrigation Methods: The manner in which water is artificially applied to an area. The methods and the manner of applying the water are as follows:

- border strip: the water is applied at the upper end of a strip with earth borders to confine the water to the strip.
- check-basin: the water is applied rapidly to relatively level plots surrounded by levees. The basin is a small check.
- corrugation: the water is applied to small, closely-spaced furrows, frequently in grain and forage crops, to confine the flow or irrigation water to one direction.

- flooding: the water is released from field ditches and allowed to flood over the land.
- furrow: the water is applied to row crops in ditches made by tillage implements.
- sprinkler: the water is sprayed over the soil surface through nozzles from a pressure system.
- subirrigation: the water is applied in open ditches or tile lines until the water table is raised sufficiently to wet the soil.
- wild-flooding: the water is released at high points in the field and distribution is uncontrolled.

Leaching: The removal of materials in solution from the soil.

Nitrification: The biochemical oxidation of ammonium to nitrate.

Nitrogen fixation: The conversion of elemental nitrogen (N_2) to organic combinations or to forms readily utilizable in biological processes.

Percolation, soil water: The downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Pesticide: A chemical agent used to control pests.

Plant nutrients: The elements or groups of elements taken in by a plant which are essential to its growth and used in elaboration of its food and tissues. Includes nutrients obtained from fertilizer ingredients.

Runoff: That portion of the precipitation on an area which is discharged from the area through stream channels. That which is lost without entering the soil is called surface runoff and that which enters the soil before reaching the stream is called ground water runoff or seepage flow from ground water. (In soil science "runoff" usually refers to the water lost by surface flow; in geology and hydraulics "runoff" usually includes both surface and subsurface flow.)

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site or origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sodium-adsorption ratio (SAR): $= \frac{Na^+}{\sqrt{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}}}$

where the cation concentrations are in milliequivalents per litter.

Soil: (i) A dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms. (ii) The collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time.

Soil alkalinity: The degree or intensity of alkalinity of a soil, expressed by a value $>$ 7.0 on the pH scale.

Soil conservation: A combination of all management and land use methods which safeguard the soil against depletion or deterioration by natural or by man-induced factors.

Soil management: The sum total of all tillage operations, cropping practices, fertilizer, lime, and other treatments conducted on or applied to a soil for the production of plants.

Soil salinity: The amount of soluble salts in a soil, expressed in terms of percentage parts per million, or other convenient ratios.

Water table: The upper surface of ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

APPENDIX C

PESTICIDES

APPENDIX C
PESTICIDES

Agricultural herbicides: types, transport modes, toxicities, and persistence in soil

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Alachlor	AM	SW	1200	2.3	40-70
Ametryne[5]	TZ	SW	1110	Low toxicity	30-90
Amitrole	TZ	W	2500	>50	15-30
Asulam	CB	W	>8000	[6] 5000	25-40
Atrazine	TZ	SW	3080	12.6	300-500
Barban	CB	S	1350	[7] 1.3	20
Benefin	NA	S	800	[6] 0.03	120-150
Bensulide	AM	S	770	0.72	500-700
Bentazon	DZ	W	1100	190	
Bifenox	AR	S	4600	1.8	40-60
Bromacil	DZ	W	5200	70	700
Bromoxynil	NT	SW	250	0.05	
Butylate	CB	S	4500	4.2	40-80
Cacodylic Acid	AS	S		[8] >40	
CDAA	AM	W	700	2.0	20-40
CDEC	CB	SW	850	4.9	20-40
Chloramben	AR	W	3500	[6] 7.0	40-60
Chlorbromuron	UR	SW	2150	0.56	
Chloroxuron	UR	S	3700	[8] >15	300-400
Chlorpropham	CB	SW	1500	[6] 10	120-260
Cyanazine	TZ	SW	334	4.9	
Cycloate[5]	CB	SW	2000	4.5	120-220
2, 4-D Acid	PO	W	370	[9] >50	10-30
2, 4-D Amine	PO	W	370	[8] >15	10-30
2, 4-D Ester	PO	S	500-875	[8] 4.5	10-30
Dalapon	AL	W	6590	>100	15-30
2, 4-DB	PO	S	300	4.0	
DCPA	AR	S	3000	>500	400
Diallate	CB	S	395	5.9	120
Dicamba	AR	W	1028	35	
Dichlobenil	NT	S	3160	10-20	60-180
Dinitramine	NA	S	3000	6.7	90-120
Dinoseb	PH	SW	5	[7, 10] 0.4	15-30
Diphenamid	AM	W	970	25.0	90-180
Diquat	CT	S	400	12.3	>500
Diuron	UR	S	3400	>60	200-500
DSMA	AS	S	600	>15	
Endothall	PH	W	38	1.15	
EPTC	CB	SW	1360	19.0	30
Fenac[5]	AR	SW	1780	7.5	350-700
Fenuron	UR	W	6400	53	30-270
Fluometuron	UR	SW	7900	[10] >60	
Fluorodifen	AR	S	15000	0.18	
Glyphosate	AL	S	4320	Low toxicity	150
Isopropalin	NA	S	5000	Toxic	150
Linuron	UR	S	1500	16.0	120
MBR 8251	AM	SW	633	312	
MCPA	PO	SW	650	10.0	30-180
Metribuzin	TZ	W	1930	>100	150-200
Molinate	CB	W	501	0.29	80
Monuron	UR	SW	3500	1.8	150-350
MSMA	AS	S	700	>15	
Naptalam	AR	W	1770	>180	20-60

*"Control of Water Pollution From Cropland," Vol. I. A Manual for Guideline Development. Agricultural Research Services, U.S.D.A. and Office of Research and Development, U.S. EPA, November 1975.

Agricultural herbicides: types, transport modes, toxicities, and persistence in soil–(continued)

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Nitralin	NA	S	2000	Low toxicity	
Nitrofen	PO	S	2630	Toxic	
Oryzalin	AM	S	>10000	Low toxicity	
Paraquat	CT	S	150	[6] 400	>500
Pebulate[5]	CB	S	921	[11] 6.3	50-60
Phenmedipham	CB	S	2000	[10] 20	100
Picloram	AR	W	8200	2.5	550
Profluralin	NA	S	2200	Toxic	320-640
Prometone[5]	TZ	S	1750	[9] >1.0	>400
Prometryne[5]	TZ	S	3750	[9] >1.0	30-90
Pronamide[5]	AM	S	5620		60-270
Propachlor[5]	AM	W	710	1.3	30-50
Propanil[5]	AM	S	1384	> 10.0	1-3
Propazine[5]	TZ	S	5000	>100	200-400
Propham	CB	W	5000	[6] 32	20-60
Pyrazon	DZ	W	2500	[12] 40	30-60
Silvex	PO	SW	375	[9] 0.36	
Simazine	TZ	S	5000	5.0	200-400
2, 4, 5-T	PO	W	300	0.5-16.7	
TCA	AL	W	3370	[13] >2000	20-70
Terbacil	DZ	W	5000	[14] 86	700
Terbutryne[5]	TZ	SW	2400	Low toxicity	20-70
Triallate[5]	CB	S	1675	4.9	30-40
Trifluralin	NA	S	3700	[6] 0.1	120-180
Vernolate[5]	CB	SW	1625	9.6	50

[1] Chemical type designations: AL, aliphatic acids; AM, amides and anilides; AR, aromatic acids and esters; AS, arsenicals; CB, carbamates and thiocarbamates; CT, cationics; DZ, diazines; NA, nitroanilines; NT, nitriles; PH, phenols and dicarboxylic acids; PO, phenoxy compounds; TZ, triazines and triazoles; UR, ureas.

[2] Where movement of herbicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, and SW denotes those that will most likely move in appreciable proportion with both sediment and water.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[4] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[5] Trade name; no corresponding common name exists.

[6] 24-hour LC_{50}.

[7] For goldfish.

[8] For killifish.

[9] For spot.

[10] LC_{100}.

[11] For mullet.

[12] For harlequin fish.

[13] For catfish.

[14] For sunfish.

Often-used trade-name synonyms of agricultural herbicides

Trade Name	Name in Table 8a	Trade Name	Name in Table 8a
AAtrex	Atrazine	Lasso	Alachlor
Alanap	Naptalam	Lorox	Linuron
Amiben	Chloramben	Maloran	Chlorbromuron
Amino Triazole	Amitrole	Milogard	Propazine
Avadex	Diallate	Modown	Bifenox
Avadex BW	Triallate	Norex	Chloroxuron
Balan	Benefin	NPA	Naptalam
Banvel	Dicamba	Ordram	Molinate
Basanite	Dinoseb	Paarlan	Isopropalin
Betanal	Phenmedipham	Planavin	Nitralin
Betasan	Bensulide	Prefar	Bensulide
Baladex	Cyanazine	Preforan	Fluorodifen
Bromex	Chlorbromuron	Premerge Dinitro	Dinoseb
Butoxone	2, 4-DB	Princep	Simazine
Butyrac	2, 4-DB	Pyramin	Pyrazon
Caparol	Prometryne	Ramrod	Propachlor
Carbyne	Barban	Randox	CDAA
Casoron	Dichlobenil	Ro-Neet	Cycloate
Chloro-IPC	Chlorpropham	Ryzelan	Oryzalin
CIPC	Chlorpropham	Roundup	Glyphosate
Cobex	Dinitramine	Sencor	Metribuzin
Dacthal	DCPA	Sinbar	Terbacil
Destun	MBR 8251	Sinox	Dinoseb
DNBP	Dinoseb	Soyex	Fluorodifen
Dowpon	Dalapon	Stam F-34	Propanil
Dymid	Diphenamid	Surflan	Oryzalin
Enide	Diphenamid	Sutan	Butylate
Eptam	EPTC	Telvar	Monuron
Eradicane	EPTC	Tenoran	Chloroxuron
Far-Go	Triallate	Tordon	Picloram
Furloe	Chlorpropham	Treflan	Trifluralin
Igran	Terbutryn	Vegadex	CDEC
IPC	Propham	Vernam	Vernolate
Karmex	Diuron		

Agricultural insecticides and miticides: types, transport modes, and toxicities

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter
Aldicarb[5]	CB	W	0.93	
Aldrin	OCL	S	35	0.003
Allethrin	PY	S	680	0.019
Azinphos ethyl[6]	OP	S	7	0.019
Azinphos methyl	OP	S	11	0.010
Benzene hexachloride	OCL	S	1000	0.79
Binapacryl	N	U	120	0.04
Bux[6]	CB	S	87	0.29
Carbaryl	CB	SW	500	1.0
Carbofuran[5]	CB	W	8	0.21
Carbophenothion	OP	S	10	0.23
Chlorbenside	S	S	3000	
Chlordane	OCL	S	335	0.010
Chlordimeform	N	W	162	1.0
Chlorobenzilate[6]	OCL	S	700	0.71
Chlorpyrifos	OP	U	97	0.020
DDT	OCL	S	113	0.002
Demeton[5]	OP	W	2	0.081
Diazinon[5,6]	OP	SW	76	0.030
Dicofol[6]	OCL	S	684	0.10
Dicrotophos	OP	W	22	8.0
Dieldrin	OCL	S	46	0.003
Dimethoate	OP	W	185	9.6
Dioxathion	OP	S	23	0.014
Disulfoton	OP	S	2	0.040
Endosulfan	OCL	S	18	0.001
Endrin	OCL	S	7.3	0.0002
EPN	OP	S	8	0.10
Ethion	OP	S	27	0.23
Ethoprop	OP	U	61.5	1.0
Fensulfothion[5]	OP	SW	2	[7] 0.15
Fonofos[6]	OP	S	8	0.03
Heptachlor	OCL	S	90	0.009
Landrin[6]	CB	SW	178	0.95
Lindane	OCL	S	88	0.018
Malathion	OP	W	480	0.019
Metaldehyde	O	W	1000	>100.0
Methidathion	OP	U	25	
Methomyl	CB	U	17	~0.9
Methoxychlor	OCL	S	5000	0.007
Methyl demeton[6]	OP	W	65	4.0
Methyl parathion[6]	OP	SW	9	1.9
Mevinphos	OP	W	4	0.017
Mexacarbate	CB	SW	22.5	1.73
Monocrotophos	OP	W	21	7.0
Naled	OP	S	250	0.078
Ovex	S	S	2000	0.70
Oxythioquinox	S	S	1100	0.096
Parathion	OP	S	4	0.047
Perthane[6]	OCL	S	>4000	0.007
Phorate[5]	OP	SW	1	0.0055
Phosalone	OP	S	96	3.4
Phosmet[6]	OP	S	147	[8] 0.03

Agricultural insecticides and miticides: types, transport modes, and toxicities–(continued)

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter
Phosphamidon	OP	W	11	8.0
Propargite[6]	S	U	2200	0.03
Propoxur	CB	W	95	[9] 0.025
TDE	OCL	S	3360	0.009
TEPP	OP	W	1	[9] 0.39
Tetrachlorvinphos	OP	S	4000	0.53
Tetradifon	OCL	SW	14000	1.10
Thionazin	OP	W	12	[7] 0.10
Toxaphene	OCL	S	69	0.003
Trichlorfon	OP	W	275	0.16

[1] Chemical type designations: CB, carbamates; N, miscellaneous nitrogenous compounds; O, cyclic oxygen compounds; OCL, organochlorines; OP, organophosphorus compounds; PY, synthetic pyrethrin; S, aromatic and cyclic sulfur compounds.

[2] Where movement of insecticides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[4] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[5] Registered as both insecticide and nematicide. Nematodes are controlled only on limited acreage and predominantly in the Southern states, but application rates when used as nematicides are 2- or 3-fold higher than when used as insecticides.

[6] Trade name; no corresponding common name exists.

[7] 24-hour LC_{50}

[8] For killifish

[9] For minnows

Often-used trade-name synonyms of agricultural insecticides and miticides

Trade Name	Name in Table 9a	Trade Name	Name in Table 9a
Acaraben	Chlorobenzilate	Imidan	Phosmet
Azodrin	Monocrotophos	Kelthane	Dicofol
Basudin	Diazinon	Lannate	Methomyl
Baygon	Propoxur	Marlate	Methoxychlor
BHC	Benzene Hexachloride	Meta-Systox	Methyl demeton
Bidrin	Dicrotophos	Mocap	Ethoprop
Cygon	Dimethoate	Morestan	Oxythioquinox
Dasanit	Fensulfothion	Morocide	Binapacryl
DDD	TDE	Neguvon	Trichlorfon
Delnav	Dioxathion	Omite	Propargite
Dibrom	Naled	Phosdrin	Mevinphos
Dimecrom	Phosphamidon	Prolate	Phosmet
Dipterex	Trichlorfon	Rabon	Tetrachlorvinphos
Di-Syston	Disulfoton	Sevin	Carbaryl
Dursban	Chlorpyrifos	Spectracide	Diazinon
Dyfonate	Fonofos	Supracide	Methidathion
Dylox	Trichlorfon	Systox	Demeton
Ethyl Guthion	Azinphos ethyl	Tedion	Tetradifon
Fundal	Chlordimeform	Temik	Aldicarb
Furadan	Carbofuran	Thimet	Phorate
Galecron	Chlordimeform	Thiodan	Endosulfan
Gamma-BHC	Lindane	Trithion	Carbophenothion
Gardona	Tetrachlorvinphos	Zectran	Mexacarbate
Guthion	Azinphos methyl	Zinophos	Thionazin
		Zolone	Phosalone

Agricultural fungicides: transport modes and toxicities

Common Names of Fungicides	Predominant Transport Mode[1]	Toxicity[2]	
		Rat, Acute Oral LD_{50}, mg/kg	Fish[3] LC_{50}, mg/liter
Anilazine	S	2710	0.015
Benomyl	S	>9590	0.5
Captafol	S	5000	[4] 0.031
Captan	S	9000	0.13
Carboxin	SW	3200	2.2
Chloranil	W	4000	5.0
Chloroneb	U	11000	>4200.0
Cycloheximide	W	2.5	1.3
DCNA	S	4040	
Dichlone	S	1300	0.047
Dichlozoline	U	3000	
Dinocap	S	980	[5] 0.14
Dodine	W	1000	0.9
ETMT	U	2000	
Fenaminosulf	W	60	23.0
Ferbam	SW	>17000	[4] 12.6
Folpet	S	>10000	[6] 1.56
Maneb	S	6750	[7] 1.0
Metiram	U	6400	>4.2
Nabam	W	395	[4] 21.1
Ocycarboxin	W	2000	
Parinol	U	>5000	[8] ~ 5.0
PCNB	S	1650	0.7
SMDC	W	820	[7] 1.0
Thiram	S	375	[4] 0.79
TPTH	U	108	
Zineb	S	>5200	0.5
Ziram	W	1400	[4] 1.0

[1] Where movement of fungicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[2] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[3] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[4] For catfish

[5] For harlequin fish

[6] For mullet

[7] LC_{100}

[8] For fathead minnow

Often-used trade-name synonyms of agricultural fungicides

Trade Name	Name in Table 10a	Trade Name	Name in Table 10a
Actidione	Cycloheximide	Phaltan	Folpet
Benlate	Benomyl	Phygon	Dichlone
Botran	DCNA	Plantvax	Oxycarboxin
Cyprex	Dodine	Polyram	Metiram
DCNA	Botran	Spergon	Chloranil
Demosan	Chloroneb	Terrachlor	PCNB
Difolatan	Captafol	TMTD	Thiram
Dexon	Fenaminosulf	Vapam	SMDC
Dyrene	Anilazine	Vitavax	Carboxin
Karathane	Dinocap		
Parnon	Parinol		

Major crops and principal pesticides registered for use on them throughout the United States

Crop	Herbicides		Insecticides and miticides	
Alfalfa	Benefin	EPTC	Azinphos methyl	Methomyl
	Chlorpropham	MCPA	Carbaryl	Methoxychlor
	2, 4-DB	Nitralin	Carbofuran	Methyl parathion
	Diallate	Propham	Carbophenothion	Mevinphos
	Dinoseb	Simazine	Demeton	Naled
	Diuron	Trifluralin	Diazinon	Parathion
			Dimethoate	Phorate
			Disulfoton	Phosmet
			Endosulfan	Toxaphene
			Malathion	Trichlorfon
Corn	Atrazine	Dalapon	Bux	Heptachlor[a]
	Butylate	DCPA	Carbaryl	Landrin
	CDAA	Dicamba	Carbofuran	Malathion
	CDEC	Dinoseb	Carbophenothion	Methomyl
	Chloramben	Diuron	Chlordane[a]	Methoxychlor
	Cyanazine	EPTC	Diazinon	Methyl parathion
	2, 4-D	Linuron	Disulfoton	Mevinphos
		Paraquat	EPN	Parathion
		Prometryne	Ethoprop	Phorate
		Propachlor	Fensulfothion	Tetrachlorvinphos
		Simazine	Fonofos	Toxaphene
				Trichlorfon
Cotton	Bensulide	EPTC	Aldicarb	EPN
	Cacodylic acid	Fluometuron	Azinphos methyl	Ethion
	DCPA	MSMA	Carbaryl	Malathion
	Dintramine	Nitralin	Carbophenothion	Methidathion
	Diphenamid	Paraquat	Chlordane[a]	Methyl parathion
	Diuron	Prometryne	Chlordimeform	Monocrotophos
	DSMA	Propachlor	Chlorobenzilate	Naled
	Endothall	Trifluralin	Demeton	Parathion
			Diazinon	Phorate
			Dicofol	Phosphamidon
			Dicrotophos	Propargite
			Dimethoate	Toxaphene
			Disulfoton	Trichlorfon
			Endosulfan	
			Endrin	
Fruit crops	Bromacil	Diuron	Azinphos methyl	Lindane
	Chlorpropham	EPTC	BHC	Malathion
	2, 4-D	Naptalam	Binapacryl[a]	Metaldehyde
	Dalapon	Paraquat	Carbaryl	Methoxychlor
	DCPA	Simazine	Carbophenothion	Methyl parathion
	Dichlobenil	Terbacil	Chlordane[a]	Mevinphos
	Dinoseb	Trifluralin	Chlordimeform	Naled
	Diphenamid		Chlorobenzilate	Ovex
			Demeton	Oxythioquinox
			Diazinon	Parathion
			Dicofol	Perthane
			Dimethoate	Phosalone
			Dioxathion	Phosmet
			Endosulfan	Phosphamidon
			EPN	Propargite
			Ethion	Tetrachlorvinphos
				Tetradifon
				Toxaphene

Major crops and principal pesticides registered for use on them throughout the United States–Continued

Crop	Herbicides		Insecticides and miticides	
Peanuts	Alachlor Benefin 2, 4-DB Dinitramine Dinoseb	Diphenamid Naptalam Nitralin Vernolate	Carbaryl Diazinon Fensulfothion Fonofos Malathion Methomyl	Monocrotophos Parathion Phorate Toxaphene Trichlorfon
Rice	Chlorpropham 2, 4-D MCPA Molinate	Propanil Silvex 2, 4, 5-T	Carbaryl Chlordane[a] Disulfoton	Malathion Methyl parathion Parathion Toxaphene
Small grains[b]	Bromoxynil 2, 4-D Diallate	Dicamba Dinoseb MCPA	Chlordane[a] Demeton Diazinon Disulfoton Endosulfan Endrin	Heptachlor[a] Malathion Methyl parathion Parathion Toxaphene Trichlorfon
Sorghum	Atrazine Bifenox CDAA 2, 4-D Dalapon	Dicamba Linuron Paraquat Propachlor Propazine	Carbaryl Carbophenothion Demeton Diazinon Dimethoate Disulfoton Ethion	Malathion Methyl parathion Mevinphos Parathion Phorate Toxaphene
Soybeans	Alachlor Barban Bifenox CDEC Chloramben Chloroxuron Chlorpropham Dalapon 2, 4-DB DCPA Dinitramine	Dinoseb Diphenamid Fluorodifen Linuron Naptalam Nitralin Paraquat Trifluralin Vernolate	Azinphos methyl Carbaryl Carbophenothion Chlordane[a] Diazinon Disulfoton EPN	Heptachlor[a] Malathion Methomyl Methoxychlor Methyl parathion Parathion Toxaphene Trichlorfon
Sugarbeets	Barban Chlorpropham Cycloate Dalapon Diallate EPTC Paraquat	Pebulate Phenmedipham Propham Pyrazon Trifluralin	Aldicarb Carbaryl Carbophenothion Demeton Diazinon Disulfoton Endosulfan EPN Fensulfothion	Fonofos Malathion Methyl parathion Parathion Phorate Trichlorfon
Sugarcane	Ametryn Atrazine 2, 4-D Dalapon Fenac	Fluometuron Simazine Trifluralin	Azinphos methyl Carbofuran Diazinon	Endosulfan Endrin Fonofos Parathion

Major crops and principal pesticides registered for use on them throughout the United States–Continued

Crop	Herbicides		Insecticides and miticides	
Tobacco	Benefin Diphenamid Isopropalin	Pebulate	Azinphos methyl Carbaryl Carbofuran Chlordane[a] Diazinon Dimethoate Disulfoton Endosulfan Ethoprop Fensulfothion	Fonofos Heptachlor[a] Malathion Methidathion Methyl parathion Monocrotophos Parathion Trichlorfon
Vegetable crops	Barban Bensulide CDAA CDEC Chloramben Chlorbromuron Chloroxuron Chlorpropham Dalapon DCPA Diallate	Dinoseb Diphenamid Endothall EPTC Flurodifen Linuron Nitralin Paraquat Propham Trifluralin Vernolate	Azinphos methyl BHC Carbaryl Carbophenothion Chlordane[a] Demeton Diazinon Dicofol Dimethoate Disulfoton Endosulfan EPN Ethion Fensulfothion Fonofos Heptachlor[a]	Lindane Malathion Metaldehyde Methomyl Methoxychlor Methyl parathion Mevinphos Naled Parathion Perthane Phorate Phosphamidon Tetradifon Toxaphene Trichlorfon

[a] Registration status under review.
[b] Wheat, oats, barley, millet, rye.

APPENDIX D

CONVERSIONS AND CALCULATIONS

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CONVERSIONS AND CALCULATIONS

Multiply	By	To Obtain
Cubic feet/second	448.831	Gallons/minute
Cubic feet/second	0.646317	Million gallons/day
Cubic feet	7.5	Gallons
Grams/liter	1000	Parts/million
Liters	1.057	Quarts
Milligrams/liter	1	Parts/Million (ppm)
Million gals/day	1.54723	Cubic feet/second
Parts/million (ppm)	8.345	lbs/million gals.
(Temp°C + 17.78)	1.8	Temp °F
(Temp°F - 32)	0.556	Temp °C

1 Kilogram = 2.205 pounds

1 Pound = 453.6 grams

1 Gallon = 3.785 liters

1 Cubic foot/sec. = 646,300 gals/day

1 Cfs = 449 gals/min.

1,000,000 gals/day = 1.547 cfs

1,000,000 gals/day = 694 gals/min.

1 Pound/million gals = 0.1199 ppm

Milligrams per liter x 8.34 x flow in mil. gals. day = lbs/day

Milligrams per liter x 3.785 x flow in mil. gals./day = kg/day

REPORTING OF LABORATORY RESULTS

Parameter	Report to Nearest	Example
pH	0.1 unit	7.2 units
BOD_5	1 mg/l	34 mg/l
TSS	1 mg/l	27 mg/l